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An International Review of Spectroscopy and
Astronomical Physics

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1901

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THE
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An International Review of Spectroscopy and Astronomical Physics

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PLATE I

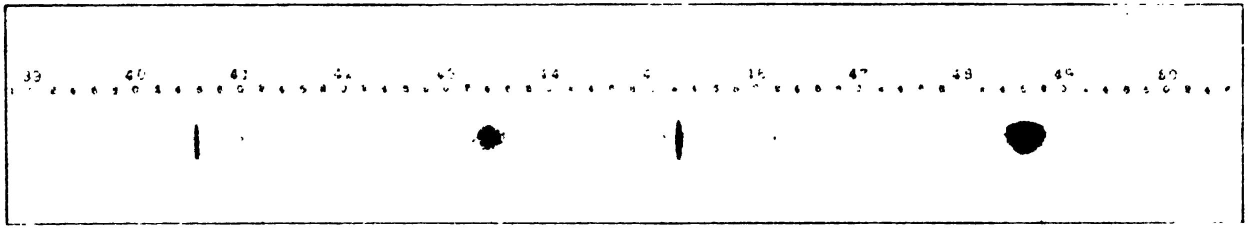

Fig. 1.—Tin Arc in Hydrogen (first order)

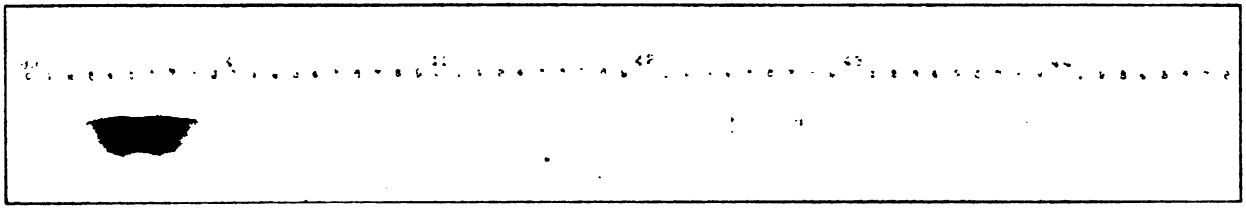

Fig. 2.—Aluminium Arc in Ammonia (second order)

THE
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VOLUME XIV JULY, 1901 NUMBER 1

THE SPECTRUM OF HYDROGEN GIVEN BY THE METALLIC ARC OF TIN, COPPER, SILVER, ETC.

By O. H. BASQUIN.

The Problem.—The arc spectra of those elements which are gases at ordinary temperatures and pressures have not been extensively studied. Their spark spectra, however, are easily obtained and were among the first to be investigated. The general impression prevails therefore that these elements do not possess arc spectra. On the other hand practically all the so-called "hot stars" and all the "new stars" possess the more important lines of the hydrogen spectrum. Although our knowledge of what is going on in the arc and in the spark is very crude and unsatisfactory, yet it is, to the average mind, much easier to imagine a star as being in a condition similar to that of the arc, rather than in one similar to that of the electric spark. It has seemed worth while therefore to search for the more important lines of hydrogen in the arc spectrum. This is the problem of the following investigation.

Historical.—Liveing and Dewar[1] examined the carbon arc in an atmosphere of hydrogen and saw "the fairly bright" *a* line of hydrogen, also "a faint diffuse band" at the position of the β line of hydrogen. They obtained these two lines also by allowing small drops of water to fall into the arc in air.[1] They found the β line usually obscured by continuous spectrum, becoming visible at intervals only, when, from some variation in the working of the arc, the continuous spectrum was less brilliant. Crew and Basquin[2] incidentally noticed these two lines of hydrogen while working with the rotating metallic arc in an atmosphere of this gas.

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[1] *Proc. Roy. Soc.*, 30, 156, 1880.

Apparatus.[3]—In searching for this line I have employed the rotating metallic arc[4] which enables one to use chemically pure electrodes having little or no chemical reaction with the gas employed. In this arc then one may expect the gas to give off its characteristic radiations with greater intensity than in one where the gas may enter into chemical compounds before a temperature is reached at which it becomes luminous. This arc enables one also to select such metals as do not have strong lines in the neighborhood of the lines sought for, while in the spectrum of the carbon arc there are few spaces not already occupied by lines of carbon or of an impurity.

In the rotating arc, one electrode, either a disk or a rod of metal, rotates upon an axis making about 700 revolutions per minute, while the other electrode has a slow movement of translation toward the axis of rotation. The rotation not only prevents the excessive heating and welding together of the electrodes, but it throws the hot gases to one side, so that the arc has the appearance of a small fan. The part of the flame, thus separated from the poles, is very free from continuous spectrum.

In the apparatus used in these experiments the arc is enclosed in a brass box or "hood" having a volume of about 1½ liters and being comparatively gas-tight. The light from the arc issues through a long brass tube closed with a lens at the outer end; the lens thus forms part of the wall of the hood but is so far removed from the arc that it receives comparatively little of the deposit sometimes formed inside the hood, and hence remains clean.

---

[1] *Proc. Roy. Soc.*, **35**, 75, 1883.

[2] *Proc. Amer. Acad.*, **33**, 18, 1898.

[3] The construction of the apparatus described below was made possible through the generous consideration of the committee of the American Academy of Arts and Sciences in charge of the Rumford Fund.

[4] CREW and TATNALL, *Phil. Mag.*, **38**, 379, 1894.

A stream of gas enters the hood at one stopcock and leaves it at another; a third cock is provided for attachment to a manometer. Although the hood is not absolutely gas-tight, the purity of the gas inside was preserved, in these experiments, partly by the small excess of pressure inside the hood above that outside, and partly by the fresh supply of pure gas constantly running through the hood. The hydrogen used was generated electrolytically and varied in quantity from 10 to 15 liters per hour.

The spectra have been examined both visually and photographically by means of a small plane grating spectroscope and by means of a large concave grating spectroscope.

Observations of hydrogen lines.—The arc spectra of the following metals in hydrogen have been examined:

Aluminium, copper, magnesium, coin-silver, sodium, tin and zinc. With the exception of sodium the arc of each metal shows to the eye very clearly the $H\alpha$ and $H\beta$ lines of hydrogen, and in most of them the $H\gamma$ line comes out with the small instrument very clearly, and indistinctly with the large one. The $H\delta$ line shows only rarely and then to the eye rather indistinctly. The $H\alpha$ line is quite sharp and well defined unless the electric current through the arc is unusually great; it has much the same appearance as the zinc line at λ 6363. The other three lines are always broad, hazy, and ill-defined.

On the photographs taken with the large spectroscope $H\beta$ and $H\gamma$ usually show very plainly, always excepting the spectrum of metallic sodium, while $H\delta$ shows in spectra of tin, silver and copper (Plate I, Fig. 2). On photographs taken with the small spectroscope these lines show more sharply on account of the very much smaller dispersion and the photographs of tin show the next hydrogen line, *Hε*, quite clearly. Not having found the hydrogen lines in the metallic sodium arc (using copper as stationary electrode), I tried this metal in dry hydrogen also, thinking that in some way the water vapor might have affected the appearance of the hydrogen lines, but I have been unable to detect any of the hydrogen lines in this arc in any way.

None of these hydrogen lines excepting *Hα* is sharply defined. A fairly wide space in the middle of the line has fairly uniform intensity, shading off very gradually and uniformly to each side. The following table gives a rough estimate of the widths, in Ångström units, of these lines as they appear on the photographic plates; the middle of the shading being taken as the edge of the line.

Line	Maximum width	Minimum width	Usual width
Hα	6	4	5
Hβ	65	13	31
Hγ	44	14	26
Hδ	32	12	20
Hε	faint, same general width.		

It will be noticed that these lines, with the exception of *Hα*, are excessively wide, and I think it is for this reason alone that I have been unable to photograph the still weaker hydrogen lines of Balmer's series. They may appear upon the plates but are so wide and so faint that they cannot be detected upon the general shading of the plates.

That these lines are not merely spark lines introduced into these arc spectra by the supposed spark at the breaking of the current through the rotating arc is shown, first, by the fact that they were first observed in the carbon arc; and, second, by the fact that I have seen *Hα* and *Hβ* quite clearly in the magnesium metallic arc, when the poles were not rotating. The lines produced in the stationary arc have much the same character as in the rotating arc, but there is a large amount of continuous spectrum, appearing as a background, in the case of the stationary arc, so that it would be difficult to photograph the hydrogen lines in this way.

These lines in the arc seem to be due to hydrogen and not to water vapor coming from the hydrogen generators.[1] This is shown by the following two experiments: (1) I passed the stream of hydrogen through concentrated sulphuric acid and phosphorus pentoxide; and even after the stream of dry gas had been running through the hood for three hours I found the *Ha* line as bright as it was in the damp hydrogen coming directly from the generators. (2) In place of the current of dry hydrogen, I passed through the hood a stream of air bubbling through warm water, so that this air was charged with moisture to about the same degree as the moist hydrogen coming directly from the generators. In this case I was not able to detect the faintest trace of the *Ha* line. Magnesium poles were used in both of the above experiments.

Other methods.—I have examined some of these metals in commercial ammonia gas, such as is used in refrigeration. In this gas the hydrogen lines come out with nearly the same intensity as in hydrogen, when copper or aluminium electrodes are used; no hydrogen lines are seen in the sodium arc in ammonia, although the arc works well, and when tin electrodes are used in ammonia a black dust collects in the atmosphere about the arc to such an extent as to shut off practically all the light within thirty seconds after starting the arc. From the standpoint of convenience and safety, the ammonia gas is much to be preferred to hydrogen.

The copper arc in coal gas shows the *Ha* line very clearly, but the other hydrogen lines are not distinguishable on account of the multitude of comparatively strong carbon lines which the coal gas furnishes in this part of the spectrum.

Following the suggestion of Liveing and Dewar, above referred to, I have tried the rotating metallic arc in air, playing a very small jet of water upon the rotating electrode. In this manner the silver arc works rather more poorly than usual, and resembles a rapid series of small explosions. The hydrogen lines come out clearly, but are rather weaker and more diffuse than in the hydrogen atmosphere.

[1] TROWBRIDGE, *Phil. Mag.*, 50, 338, 1900.

The copper arc works well in an atmosphere of steam, much better than in hydrogen. The hydrogen lines are nearly, if not quite, as strong in steam as in hydrogen. The electrodes of the arc are slightly oxidized, and have very beautiful colors. In making this experiment a slight alteration was necessary in the hood of the arc. The window through which the light issues is usually as far away from the arc as possible, but it was moved for this experiment so as to be as close to the arc as possible. It was placed at the inner end of a brass tube projecting into the hood, in order that the heat of the surrounding steam and hot air, as well as that of the arc itself, might prevent condensation of steam upon the surface of the window.

CHEMICAL ACTION IN THE ARC IN HYDROGEN.

Historical.—Crew and Basquin[1] have sought to eliminate the radiations due to chemical causes in the electric arc by using chemically pure metallic electrodes and enclosing the arc in an atmosphere of hydrogen or nitrogen. They interrupted the current through the arc about 110 times per second and examined the light of the arc while the current was null. They found in the rotating metallic arc *in air* "a luminous cloud" persisting for several thousandths of a second after the current through the arc had ceased, but they found no such luminous effect in an atmosphere of hydrogen or nitrogen. This seems to show that the cloud is due to chemical action going on in the gases after the electric current has stopped, and that in hydrogen the chemical action is too feeble to be noticed in this way.

Liveing and Dewar[2] found a magnesium "line" at λ 5210 making its appearance in the arc spectrum only upon the introduction of hydrogen or coal gas into the arc. Professor Crew[3] gives a number of lines appearing in the iron arc in hydrogen and not appearing in the arc in air.

Hydrogen-metal Flutings.—With the exception of tin, every metal thus far examined in the rotating metallic arc in hydrogen

[1] *Proc. Amer. Acad.*, 33, 18, 1898.

[2] *Proc. Roy. Soc.*, 30, 96, 1880.

[3] *Phil. Mag.*, 50, 497, 1900.

gives a characteristic set of spectrum lines which are not found in the arc in air. Inasmuch as compounds of hydrogen with some metals are known, I have, in lieu of a better hypothesis, supposed that these lines are due to such compounds formed in the arc. No new isolated lines, surely due to hydrogen, have been found. The following description takes up the metals in the order of the relative intensities of these flutings:

Tin.—No fluting has been discovered due to a combination of tin and hydrogen. There are four lines of intensity ½ on Rowland's scale at approximately λ 3715, 3841, 4245, and 4386, which have not yet been identified. These may be weak tin lines not listed, or weak impurity lines. The deposit which is formed in the hood enclosing the arc is very small in amount and of a greenish color, and consists of very small globules of metal. If this deposit is heated upon platinum-foil in a Bunsen flame it quickly glows and thereafter has a slate color, and if this powder is placed in hydrochloric acid it dissolves when heat is applied and gives off bubbles of gas. If the dark powder, after the first heating, is reheated on foil in the flame, it glows again apparently at a higher temperature than before, and then becomes a very white powder, both of which experiments go to show that the original powder is not metallic tin, but is possibly some combination of tin and hydrogen.

Coin silver.—This metal gives a delicate fluting with first head at λ 3333.86 and running toward longer wave-lengths. There are only about fifty lines in this fluting and they have an average intensity rather less than ½ on Rowland's scale.

Copper.—This metal gives a rather open fluting having the head at λ 4279.77 and running toward the longer wave-lengths. The number of lines in this fluting is about sixty and they are individually stronger than those of the coin silver fluting. This fluting makes its appearance also when an atmosphere of ammonia or of steam is used. The deposit formed inside the hood is rather small in amount and of a brown color. The following table gives the wave-lengths of the hydrogen-copper fluting:

Wave-length	Intensity	Remarks	Wave-length	Intensity	Remarks
4279.77	2	Head	4332.98	1−	
4280.72	1		4335.20	1+	
4281.25	1+	Ghost of 4275 ?	4339.80	1−	
4281.85	1+		4341.98	1+	
4282.48	½		4347.06	1−	
4283.38	1+		4349.13	1+	
4284.15	½		4354.59	1−	
4285.26	1+		4356.73	1+	
4287.58	1+		4364.68	1+	
4290.25	1+		4373.01	1+	
4293.45	1+		4381.70	1+	
4294.86	1−		4382.92	½	Hazy
4296.98	1+		4384.74	1−	
4298.55	1−		4390		Very indistinct
4300.92	1+		4390.85	1+	
4302.63	1+		4400.30	1+	
4305.24	1+		4405.04	1−	
4307.07	1+		4410.12	1+	
4309.98	1		4413.00	½	
4311.89	1+		4420.42	1+	
4315.12	1		4421.59	1−	
4317.07	2	Slight shading toward blue	4430.94	1	
4320.68	1−		4436.48	1	
4322.74	1		4447.18	½	
4324.59	1+		4453.30	1	
4326.61	1		4458.03	1	
4328.77	1+		4465.01	1	
4331.38	½	Hazy	4477.15	1−	

Aluminium.—The aluminium arc in hydrogen gives a beautiful fluting with first head at λ 4241.26 and running toward longer wave-lengths. This fluting appears equally well in an atmosphere of ammonia (Plate I, Fig. 2). The following table gives the wave-lengths and intensities of the principal lines:

Wave-length	Intensity	Remarks	Wave-length	Intensity	Remarks
4241.26	3	1st head	4292.01	2	
4241.75	3		4294.31	3	
4242.41	2		4296.99	2	
4243.10	2		4298.10	3	
4243.94	3	Wide	4302.08	3	
4245.32	4		4302.65	1	
4246.58	3		4306.34	3	
4247.58	1		4310.82	3	
4248.09	2		4315.57	3	
4249.68	2		4320.63	3	
4250.34	1		4326.00	5	Impurity superposed
4251.44	2		4331.91	2	

Wave-length	Intensity	Remarks	Wave-length	Intensity	Remarks
4253.26	2		4338.37	2	
4255.22	2		4345.34	1	
4257.35	1+		4353.38	2	4th head
4259.71	3	Wide, 2d head	4354.13	1	
4261.18	3		4355.17	1	
4261.77	3		4356.64	1	
4262.59	3		4361.30	1	
4263.50	3		4362.21	1	
4264.58	3		4363.30	1	
4265.80	3		4365.18	2	
4267.24	3		4367.21	2	
4268.86	3		4368.	½	
4270.68	3		4369.67	2	
4272.72	3		4371.49	½	
4274.98	5	Impurity here	4372.54	1	
4277.70	4	Impurity here	4375.18	½	
4280.67	4		4375.97	1	
4283.94	4		4379.19	½	
4287.30	2	3d head?	4379.90	½	
4287.75	3		4388.23	1	
4289.91	3		4393.42	1	
4290.68	2		4399.19	1	

Magnesium.—The magnesium arc in hydrogen gives the three flutings discovered by Liveing and Dewar[1] in the magnesium-hydrogen spark, with first heads at λ 5618, 5210, and 4849 and running toward the *shorter* wave-lengths. The fluting at 5210, which is the one showing the plainest on my photographs is made up of such very fine lines near the heads that the principal head appears like a line by itself; but farther away from the heads the lines seem to become stronger and to overlap one another so that many of these lines are much stronger than the head itself and their distribution seems quite irregular. I mention this more particularly because it is characteristic of the hydrogen-zinc and hydrogen-sodium flutings described below. I have noticed that in the spark, the intensity of the magnesium flutings is greatly increased with respect to that of the *b* group by the introduction of inductance in series with the capacity shunted about the induction coil. The deposit in the hood enclosing the magnesium arc in hydrogen is quite plentiful, has a dark slate color, decomposes water at ordinary temperature, giving alkaline reaction, and oxidizes rapidly on heated platinum.

[1] *Proc. Roy. Soc.*, 32, 189, 1881.

Zinc.—The zinc arc in hydrogen gives a collection of lines between about λ 4300 and 4050, having an average intensity from 2 to 4, and not found in the arc in air. This appears to be a set of flutings of complicated structure having heads less distinctly marked than usual and running toward the shorter wave-lengths. The semi-opaque deposit formed in the atmosphere of the hood is so considerable that a current of not more than about four amperes can be used. This deposit is dark brown in color, gives alkaline reaction in water, but does not decompose it enough to form bubbles even when heated. It dissolves completely in sulphuric acid, forming a clear solution, and rapidly oxidizes on heated platinum.

Sodium.—The sodium spectrum was obtained by using metallic sodium as the cooler rotating electrode, and copper as the stationary one. As above mentioned, there is not the slightest trace of any of the hydrogen lines to be detected in this spectrum, either visually or on the photographs, but there is a strong series of lines, between λ 5000 and 3800, resembling the magnesium-hydrogen series in character. This is probably a complicated fluting of heads less clearly marked than usual and running toward the shorter wave-lengths. A compound of sodium and hydrogen is already well known. The formation of the semi-opaque deposit in the atmosphere of the hood is so considerable that the arc can be run only about five minutes at a time. I have not tried the sodium arc in air.

The sodium spectrum obtained in hydrogen is itself quite interesting. All the sodium lines given by Kayser and Runge come out very clearly, but the principal interest centers about the D lines, which are very intense, and so wide as to cover all the region between them. When observed visually their reversals change in width quite rapidly. At first these reversals may be quite narrow black lines, and then they quickly widen and blot out the whole of the bright field between them. The width of the two lines taken together is about 150 Ångström units, though the photographic plates are stained for a much

---

[1] KAYSER and RUNGE, *Wied. Ann.*, 41, 302, 1890.

greater width. The strongest copper lines show only very faintly, the weaker ones not at all.

Correlation of Effects.— In the metals arranged in the order given above (tin, silver, copper, magnesium, aluminium, zinc, and sodium) the following relations roughly hold:

(1) The set of lines characteristic of the spectrum of each metal in an atmosphere of hydrogen is stronger than that of the *preceding* metal of the series; (2) the hydrogen lines appearing in the spectrum of the metallic arc of each metal are stronger than in that of the *succeeding* metal of the series; (3) the general working of the metallic arc is worse for the metals at the first of the series than for those at the end. Briefly stated, the intensities of the hydrogen lines coming out in the spectra of various metals are roughly inversely proportional to the intensities of the characteristic flutings of those metals.

GENERAL EFFECTS OF THE HYDROGEN ATMOSPHERE.

Historical.—Liveing and Dewar[1] found the carbon arc to work badly in hydrogen, and to give spectral lines of different relative intensities than in air. Professor Crew[2] has given quantitative measurements of these changes of intensities for the metallic arc spectra of magnesium, zinc, and iron.

The general effects of the hydrogen atmosphere may be summarized thus:

(1) The arc works poorly in hydrogen. (2) The intensity of the whole spectrum is greatly reduced in hydrogen. (3) Those metallic lines which belong to the series of Kayser and Runge are uniformly reduced in intensity. (4) Other lines are reduced in intensity but not uniformly. (5) Certain lines supposed to belong to the spark spectrum make their appearance in the arc in hydrogen.

Discussion.—The radiations of the electric arc are generally admitted to be due to three causes: electrical, chemical, and thermal. The chemical cause must depend upon the electrical cause in some way, for the chemical cause cannot originate the arc, and the chemical cause follows the electrical in point of time, as is shown by the "luminous cloud" of Crew and Basquin above referred to. The thermal cause also must depend upon the electrical cause in some way. It probably depends upon it directly, but, in any event, it is a function of it through the chemical cause, for all chemical reactions either take in heat or give off heat.

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[1] *Proc. Roy. Soc.*, 33, 430, 1882.

[2] *Phil. Mag.*, 50, 497, 1900.

Let us consider two arcs which are alike except that a larger current runs through the first than through the second. Since the secondary causes of radiation go hand in hand with the electrical cause, we may expect the first arc to have a spectrum which is uniformly brighter from one end to the other than that of the second arc. With the exception of a slight variation, probably due to conduction losses, this is just what is always observed, and confirms the secondary character of the chemical and thermal causes of radiation. If these causes were not dependent upon the electrical causes, we might possibly get an arc which would give only a flame spectrum, or an arc which would give only a spark spectrum.

Let us now suppose that we run the same current through both the similar arcs, and suppose that in some way we reduce the chemical action going on in the second arc. What difference may we expect to observe in them?

A reduction of the chemical action necessarily involves a reduction of the temperature of the arc, because the chemical reaction in the arc in air is exothermic. We have then an arc of lower temperature. If it is a stationary arc it will be shorter and will go out more frequently. If it is rotating it will have a smaller flame and work more poorly. All of which is amply verified by experiments in hydrogen.

But we may expect this reduction of chemical action to have certain effects upon the spectrum. If all the lines of the spectrum of this arc were functions of the *electrical cause alone*, then there would be *no reduction* in intensity of any part of the spectrum when the chemical action is reduced. Professor Crew estimates from five to one hundred times as the reduction in intensity caused by the hydrogen atmosphere. The electrical cause alone can account, then, for only a small part of the radiation. The secondary causes play very important parts.

If all the lines of the spectrum of this arc were the *same function* of the causes of radiation, then all the lines of the spectrum would be *uniformly* reduced in intensity upon the reduction of chemical action. Experiment shows this hypothesis to be too broad, but the lines belonging to the series of Kayser and Runge are uniformly reduced in intensity, so that it is *probable* that these lines are all the same function of the causes of radiation.

Of the other lines those which are reduced more in intensity than the series lines must be less intimately related to the electrical or thermal causes of radiation than are the series lines.

Let us agree that the average intensity of the spectrum of the arc in hydrogen is only one fifth of its intensity in air, and let us agree that the electrical cause of radiation remains practically constant with constant current and voltage although the general intensity of the arc is greatly reduced by the hydrogen atmosphere, then it follows that of the total radiation, that fraction which must be attributed to the electrical cause alone, is relatively five times as great in hydrogen as it is in air. Any line, therefore, which is a function of the electrical cause alone, should have in hydrogen five times the relative intensity that it has in air. It seems quite likely that this may account for the appearance in hydrogen of numerous strong spark lines, not found in the arc in air.

The appearance of the spark lines in hydrogen is not confined to the rotating arc; the magnesium spark line at λ 4481 appears clearly in the stationary metallic arc in hydrogen but not in air. The above explanation for the appearance of these lines makes it probable that the electrical cause of radiation is not zero in either atmosphere.

In the rotating arc the current is interrupted about twenty-five times per second when the rotating electrode is a rod, instead of a disk, of metal, and this spark at the breaking of the current may account, in part, for the appearance of these spark lines in hydrogen. But we may inquire why this spark should partake any more of the nature of the true spark in hydrogen than in air? The reduction of the chemical action in the arc reduces the temperature aud conductivity of the gases between the poles in hydrogen and it occurred to me that this action may affect the appearance of the spark lines in either of two ways:

1. It may be that a gas which is in the hot condition of the arc in air cannot give off spark lines; the arc spectrum may be characteristic of this condition of the gas and may have nothing to do with electrical action and so, in this state, would give off only arc lines if a spark were passed through it.

2. It may be that the conductivity of the gases in air is reduced so slowly at the breaking of the current in the rotating arc that the voltage of break never rises high enough to make a true spark.

In either of these cases, in hydrogen, the hot gases are largely absent owing to reduction of chemical action and give opportunity for the spark to appear.

In order to test the first suggestion I arranged an electrical circuit as shown in the diagram. The dynamo furnishes a direct current of 110 volts and when the switch was closed the current simply passed through the arc and the resistance in series. The arc was stationary, one electrode was carbon and the other a zinc rod. The induction coil used is a duplicate of the one designed by Professor Rowland to give a short spark but a very powerful discharge; an alternating current of 110 volts, 6 amperes, was run through the primary, without an interpreter. The condenser used has a capacity of $\frac{1}{60}$ microfarad. It will be noticed that the spark can take place only by passing in succession the two gaps marked "arc" and "spark." The

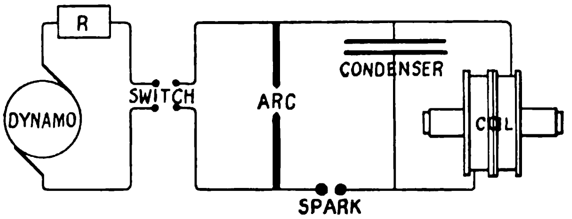

FIG. 1.

spectroscope is adjusted to observe the phenomena taking place at the gap marked "arc."

In performing this experiment I first turned on the spark and set the cross-hairs of the eyepiece of the 10-foot concave grating upon the zinc spark line at λ 5895, between the D lines of sodium. The spark was turned off and arc turned on. The spark line no longer appeared but came out instantly when the spark was again started along with the arc; both arc and spark were now running through the gap marked "arc" and the spectroscope showed both arc and spark lines. Now while both currents were on, the arc current was turned off; the arc spectrum disappeared but the spark spectrum persisted with apparently the same intensity as before and without any interval of darkness.

This experiment shows that the first suggestion is not true; that the arc spectrum is not characteristic of the condition of the gases in the arc, and makes it highly probable that the electrical cause of radiation is not zero.

In order to test my second suggestion above, I short circuited the spark gap shown in Fig. 1. The spark lines appeared as before in the spark, but disappeared as soon as the arc circuit was made; the arc and the spark discharges were both passing through the arc as before; I had simply cut out the "spark" gap, but the spark lines could not be seen when both currents were on. Now, when both currents were on, I broke the arc circuit, and nothing at all could be seen in the spectroscope; neither the arc nor the spark lines remained, although the spark current was still passing. After remaining at the eyepiece of the spectroscope about one second I began to see traces of the spark lines and then they soon came out with their usual brightness, and the spark discharge, which had been silent during that second of darkness assumed its usual noisy character.

This experiment shows that the gases of the arc do not furnish enough resistance to the passage of a high voltage alternating current to cause the discharge to assume the character of a spark for a full second after the breaking of the arc current. This seems to confirm the second suggestion of page 14, to the effect that the conductivity of the gases decreases so slowly in the breaking of the arc current in air as to give rise to no very high voltage, and so accounts for the non-appearance of the spark lines in the rotating arc in air.

These two experiments throw an interesting light upon the nature of the spark. The spark at the arc gap in these experiments seems to be due to neither the current nor to the voltage, but to some kind of an impulse furnished by the sudden rush of electricity across the auxiliary "spark" gap.

In the second experiment above described, the spark lines do not all seem to come out at the same time. I hope in the near future to be able to arrange an automatic apparatus for making and breaking the currents and an adjustable occulting-screen which will enable one to photograph the spectrum of the spark at definite intervals of time after the arc current is broken. A series of these photographs will probably furnish an interesting story of the development of the spark spectrum.

ON A POSSIBLE FUNCTION OF DISRUPTIVE APPROACH IN THE FORMATION OF METEORITES, COMETS, AND NEBULAE.[1]

By T. C. CHAMBERLIN.

ACCORDING to a familiar doctrine founded on the researches of Roche, Maxwell, and others, a small body passing within a certain distance (the Roche limit) of a larger dense body will be torn into fragments by differential attraction. In reality, the doctrine is applicable to the close approach of any two bodies of sufficient mass and density, but, as this more familiar case of a small body in close approach to a larger body is the one supposed to be involved in the origin of comets and certain meteorites, it will at first be taken as representative, and the wider application of the doctrine will be considered later.

The sphere defined by Roche's limit is computed on the basis of a liquid body whose cohesion is negligible, and whose self-gravitation alone is considered. It is obvious, therefore, that when cohesion is a notable factor, a small body might pass through the outermost part of this Roche sphere without suffering disruption, but that, if a nearer approach were made to the large body, fragmentation might take place. There is, therefore, a sphere within the Roche limit—which may be called the sphere .of disruption—which is applicable to solid bodies as distinguished from liquid bodies.

The size of this sphere of disruption compared with the Roche sphere depends, among other things, on the coefficient of cohesion and the size of the body to be disrupted. The coefficient of cohesion being the same, the sphere of disruption is relatively smallest when small bodies are to be disrupted, and becomes larger as the size of the body increases until it is sensibly as large as the Roche sphere. To illustrate this concretely, let disruptions be supposed to take place along a diametrical section normal to the gravitative pull, dividing the body into halves. Let the bodies to be disrupted be spherical and homogeneous. The cohesion to be overcome will then obviously vary as the areas of the diametrical sections, and these areas vary as the squares of the radii of the bodies. But the masses of homogeneous spheres vary as the cubes of their radii, and the gravitative pull varies as the masses, modified by the differential tidal pull. It follows that mutual gravitation will more effectively disrupt large bodies than small ones. The limit at which the fragmentation of a solid body will take place will therefore approach more and more closely that of a fluid body as the size of the solid body becomes larger. For solid bodies of considerable dimensions, as asteroids, for example, the limit of disruption approaches sufficiently near Roche's limit to make the difference negligible in a general discussion. This will appear the more evident from the following numerical considerations.

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[1] I am greatly indebted to Dr. F. R. Moulton for suggestions and criticisms, and for formulæ for certain auxiliary computations that do not appear in the paper. I am under obligations to Mr. C. E. Siebenthal for the diagrams and other aid.

Experimental data as to the tensile strength of rock are very limited, as the material is rarely used where tensile stresses are involved, but all the results of experimental tests given in Johnson's *Material of Construction* fall notably below 1000 pounds to the square inch, and this figure may be assumed as a liberal representative estimate. The weight of representative rock may be taken as $\frac{1}{10}$ pound per cubic inch. The tensile strength of an inch cube is therefore to its weight, at the surface of the Earth, as 10,000 to 1. Using the same data, the tensile strength of a mile-cube of rock is to its weight as 1 to 6.36, while that of a 100-mile-cube is as 1 to 636. It will be seen, therefore, that in a comparatively small body the cohesive resistance to disruption bears a very small relation to the gravity of the mass, and that for large bodies it is negligible. For such bodies, the Roche limit may be taken as appreciably the limit of the sphere of disruption.

These numerical considerations, however, show that fragmentation by differential gravity acting alone will not become minute in any such case as that of a satellite or asteroid making a near approach to one of the planets.

But there are additional considerations that influence the practical result. The outer portion of the Earth, and doubtless that of the satellites, asteroids, and cold planets generally, is deeply traversed by fissures—oblique and horizontal as well as vertical—which render it little more than a pavement of dissevered blocks which could be lifted away with little resistance beyond that of gravity. The relief of pressure upon the less fissured portion below, which would follow upon the removal of the overlying fissured portion, and the sudden exposure of this under portion to a lower temperature resultant from this removal, would develop new stresses; and these would doubtless give rise to additional fissuring and further easy removal, and thus the process would be extended. It is not improbable that the sudden rending open of a sphere that is hot within and the consequent exposure of the highly heated rocks in the interior to much lower temperatures would result in sufficiently great differential contraction to minutely disrupt the fragments irrespective of differential gravitation. The central portions of a body sufficiently hot to melt at surface pressures would doubtless pass immediately into the liquid condition on the removal of the pressure of the overlying rock, and this passage might, not unlikely, take on eruptive violence by reason of the included and highly compressed gases—or substances in a potentially gaseous state—in which case an extremely minute division would ensue. In the case of the Earth, there is good reason to believe that if its interior gravitative stresses were suddenly removed, its internal elasticity would disrupt its exterior with much violence; and if the gravitative stresses were more gradually removed, the disruption would still be complete and pervasive, though less violent. How far a similar view may be entertained with reference to small bodies like the asteroids is uncertain, but even in these it is not improbable that the internal elastic factors would offset in some large part, if not entirely, the restraining force of the general cohesion of the mass.

From these considerations it would seem that the sphere of disruption, even in solid bodies of the nature of satellites and asteroids, may closely approximate to the theoretical Roche limit, while, for large bodies intensely compressed and very hot within, the practical sphere of disruption might actually exceed the Roche sphere. In the case of large gaseous bodies like the Sun, intensely heated and compressed in the central portions, the disruptive or dispersive sphere must be much larger than the Roche sphere. But of this later. For the smaller solid bodies, and for present purposes, it may be assumed that the sphere of disruption is practically defined by Roche's limit.

The size of the sphere of disruption compared with the size of the body producing the disruption is an essential point in this discussion. The relative magnitude of these varies for every couplet of bodies brought under consideration, because it is dependent on density, cohesion, internal elasticity, and other varying factors. Roche has shown that, if the two bodies are incompressible fluids of the same density, and without cohesion, the limit of disruption is 2.44 times the radius of the body producing the disruption. The cross section of this body will therefore be to the cross section of the Roche sphere as 1 is to 5.95. The disk of the outer ring of *Saturn*, compared with that of the planet, whose density is unusually low, is a trifle below this ratio (1:5.29), but may be taken as a practical sanction of the figure theoretically deduced. The disk of the Earth, a dense body, is to the disk of the Roche limit, as computed by Darwin, as 1 to 7.5. It may therefore be concluded that where planets and planet-like bodies are concerned, the sphere of disruption has a cross section from 5 to 7.5 times as great as the central body. It follows from this, that to a passing body the sphere of disruption exposes a disk five to seven times as great as the central body, and hence there are from four to six times as many chances that the passing body will invade the sphere of disruption without collision, as that it will strike the central body. In other words, *the fragmentation of a small body by near approach to* *a large one of the nature of the planets will be from four to six times as imminent as actual collision.*

That disruptions or explosions of some kind actually take place in the heavens, and that not uncommonly, seems to be implied by the sudden appearance of new stars, often with great brilliancy, followed by rapid decline to obscurity or extinction.[1] Five such new stars have been recorded during the last decade, and the survey of the heavens during this period has not been entirely exhaustive. The appearance of such new stars has been referred to collision, but their frequency has been felt to be an objection to this view, and other explanations, of the nature of eruptions or explosions, have been offered, but usually without assigning any probable cause for such extraordinary explosive action. The numerical objection is, in some measure, removed if the possibilities of disruptive approach be added to those of collision; and it will be seen further on that special conditions giving rise to distant approaches that are merely disturbing at the outset, may ultimately give rise to large possibilities for disruptive approaches.

That bodies pass within the disruptive sphere of other bodies is known from the fact that at least four comets have been observed to pass within the Roche limit of the Sun, and these would quite certainly have been torn into fragments if they had not already been in that condition. There are, therefore, some observational grounds for the view that instances of bodies passing through the disruptive spheres of other bodies are not so rare as to render their results unimportant.

In the considerations now set forth, there seems to be warrant for the proposition *that solid bodies may suffer fragmentation without actual collision with other bodies, and that the bodies so disrupted may constitute comets so long as the fragments remain clustered, and that when these fragments become dispersed, they may constitute one variety of meteorites.* Only the first part of the proposition is novel—if indeed that is—for the disintegration of comets into meteorites is an accepted doctrine. The characteristics of comets other than their fragmental structure will need to be considered, but this may best be taken up later.

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[1] A fact which has become very familiar and impressive, since this was written, by the appearance of *Nova Persei.*

The foregoing conclusion, as a purely ideal proposition, does not appear to need discussion, unless the fundamental deductions of Roche, Maxwell, and others are questioned. Nor does its application to the adventitious cases of wandering bodies permit definite discussion, for neither the nature nor the number of such bodies is known; nor is the likelihood of their close approach to other bodies capable of estimation. But, on the probable supposition that the stars are centers of systems like our Sun, there are hypothetical cases of approach of these systems to each other that by disturbance of the planetary orbits may lead on to disruptive approach of the individual bodies, and thus give effective application to the doctrine; and these invite consideration. It must be confessed that these cases, likewise, cannot be discussed with much satisfaction, since the movements of the assumed solar systems and their relations to each other are but very imperfectly known. Present data, however, warrant the assumption that the stars and their attendants are moving in various directions at various velocities, and that they are probably not controlled by any central body; nor do they probably follow concentric orbits so adjusted to each other as to forbid close approaches. The conception that the movements of the stars are somewhat analogous to those of the molecules of an exceedingly attenuated gas in an open space, actuated by the attraction of their common but dispersed mass, seems the most probable that can be entertained in the present state of knowledge. It may at least be made the basis for the assumptions necessary to further discuss the doctrine in hand.

Let two stars be assumed to be attended by secondaries like those of the Sun, and to pass each other near enough to initiate serious disturbances in the orbits of the planets and satellites of the two systems. It is not necessary that this disturbance shall be so great as to bring about a disruptive approach of any of these bodies at once, but merely that this shall be the ulterior effect, which may be long delayed. The two systems need not necessarily invade each other's actual limit, that is, the two suns need not approach each other within the sum of the radii of the orbits of their outermost planets.[1] For example, in the ideal case of two solar systems, it is not necessary that the orbits of the two *Neptunes* shall actually cut each other. If the undisturbed orbits merely touch each other, or even closely approach each other, it seems clear that if *Neptune* be at the time coming toward the point of such ideal contact, or near approach, the attraction of the passing sun, together with *Neptune's* own momentum, will carry the planet far beyond the limit of its own ideal orbit into the sphere of dominant influence of the passing sun. At the same time, the paths of the inner orbits of both systems will be distorted in a quite irregular way, dependent on their various positions in their several orbits. The transfer of an outermost planet from one system to another under these conditions of general disturbance, or any other radical change in the orbits of the outer planets, will quite certainly lead on to other disturbances of orbit, some of which may sooner or later lead to disruptive approach, though the result of such a complication is beyond the reach of precise prediction.

A still more remote approach between two systems in which the only result is a pronounced elongation of the orbits of the two systems, may ultimately result in close approaches, for, if the orbit of any of the planets of the two systems be elongated so that its perihelion distance is less than the aphelion distance of the next inner planet, or its aphelion distance greater than the perihelion distance of the next outer planet, a disruptive approach, although it will not necessarily follow, because the planes may not coincide, and for other reasons, may result — if not at once, at least ultimately — as a consequence of the shiftings and modifications which such a disturbed condition involves. For example, it is obvious that by a favorable conjunction with a passing system whose sun is distant from *Neptune* considerably more than the radius of his orbit, there may be an elongation of the orbit of *Neptune* so as to make it cut one or more of the inner orbits, and that further modifications may arise out of these relations which will either increase or decrease the eccentricity. The principles applicable here are identical with those that have been found to produce radical modifications of the orbits of comets and that have been worked out by H. A. Newton and others.

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[1] In the illustrative examples it is assumed for convenience that the planes of the systems are normal to the systems' lines of movement.

To embrace the full possibilities of the case, it is therefore necessary to consider (1) the effects of systems passing each other at distances varying from those in which the outermost planets do not even cut each other's orbits, down to center-on-center collisions, and (2) to take account of the ulterior effects of disturbed orbits, as well as the immediate effects. This last is a consideration of no small importance in the qualitative as well as the quantitative application of the doctrine, for it distributes the effects over an indefinite period of time, and does not require their coincidence with the passage of the systems. The ulterior effects, so far as the disruption of secondaries is concerned, may apparently be much greater than the immediate effects. If this is not already clear, let a specific case be taken, as, for example, two solar systems passing each other so that their centers shall be 500,000,000 miles apart at nearest approach. If the planes of the systems are transverse to their paths, the ideal undisturbed orbits of the asteroids will touch, or closely approach, or slightly cut each other, as the individual case may be. The ideal orbits of the *Jupiters* will fall but little short of the passing sun, while the ideal orbits of *Saturn*, *Uranus*, and *Neptune* will fall outside the passing sun. While the precise results of such an event cannot be computed, it is quite certain that the secondary systems of the two suns will be most profoundly disturbed and the symmetrical and harmonious relations of the planetary orbits be utterly broken up. While even in this case the *immediate* contingency of a disruptive approach of one secondary to another may not be high, there will arise a *perpetuated series of contingencies*, the consequences of which will apparently be immeasurably greater than those immediately incident to the disturbing action, and the end of this perpetuated series of contingencies can scarcely be foreseen. Assuming that the great planets will exercise the same kind of influence over the small planets and asteroids that pass near them that *Jupiter* does over comets, the range of possible contingencies involves, on the one hand, closer and closer approaches and even collisions with the Sun and with other planets, and, on the other hand, the development of extremely elliptical orbits that will carry the small bodies into the sphere of influence of some other system. How large a proportion of these theoretical possibilities will be realized in a given disturbed system, it is impossible to determine, for the problem is far beyond the power of mathematical analysis, but it seems at least probable that results of moment may ensue.

If we may judge from the solar system, the small bodies may be assumed to be at least fifty times as numerous as the large ones, while not improbably they are a hundred or several hundred times as numerous. Other things being equal, they should show the characteristic effects of the action under discussion with correspondingly greater frequency. But the other conditions intensify these effects. A small body may be disrupted by a large one, but not necessarily the reverse. So, too, a small body may be thrown into an erratic orbit, while the orbit of the large body may not be sensibly affected, as shown by the changes in the orbits of comets caused by *Jupiter.* By far the most common effect of the close approach of two star systems should therefore be the fragmentation of the small bodies by being caused to pass within the spheres of disruption of the large bodies. As previously indicated, *the contingency of acquiring at the same time highly erratic orbits is imminent, and these are specially subject to still further changes, and thus these fragmental clusters come to possess by the very circumstances of their birth the second characteristic of comets, as well as the first.*

Whether they would possess at the same time, or come at length to possess, the *third* characteristic of comets, the attenuated matter of which cometic tails are made, is not so clear, since the nature of this matter and its condition are not yet fully known. The recent discoveries relative to the extreme ionization of matter and perhaps even its corpuscular dissociation, and the radio-activity of certain kinds of matter are at least very suggestive in this connection. Six of the elements reported by good authority as detected in meteorites, are known to possess, or to be habitually associated with, radio-active matter, viz., barium, bismuth, cerium, lead, titanium, and uranium. It is not very material here whether this radio-activity is really possessed by all these elements themselves, or simply by substances associated with them. If the coma and tails of comets are dependent on rare substances of a radio-active or extremely volatile nature, and hence permanently retensible only in the interior of bodies, it would be difficult to imagine conditions more favorable for setting them free in unusual volume than minute tidal disruption; particularly is this true if the retention of these substances is dependent on low temperature, as seems to be the case, since they are brought forth and driven away at a highly accelerated rate as the Sun is approached. This view seems also to be supported by the fact that comets which remain long in the vicinity of the Sun, as for example the short-period comets, lose their tails in a brief period.

If the attenuated cometic matter owes its essential peculiarities to electric states, these might perhaps be derivable from the revolutionary movements of the magnetic elements in the fragmental swarm, for by the hypothesis of tidal disruption the swarm should inherit a rotatory movement, and the fragments should contain both magnetic and magnetizable matter, variously associated with diamagnetic matter.

That short-period comets are subject to progressive disintegration, and that their scattered elements constitute one class of meteorites, is familiar doctrine. There seems no reason for withholding the conception from comets which have parabolic or hyperbolic orbits, for in certain cases such comets have shown signs of disruption and partial dispersion in their perihelion passages. To the dispersed elements of these comets of high velocity is assigned (in part at least) such meteorites as come to Earth from diverse directions with velocities incompatible with an origin within the solar system.

It remains to consider whether the fragments derived from the disruption of an asteroid, satellite, or small planet through differential gravitative strain without collision, will satisfy the characteristics which meteorites display. Ample data for a judgment on this vital point will be found in the articles on the structure of meteorites in the first two numbers of the *Journal of Geology* for the current year, by Dr. Farrington, who, at my request, has kindly brought together in succinct and systematic form the essential characteristics of meteoric structure. A study of these characteristics will show that, while they embrace a great and very significant variety, they are all referable to the structures that are appropriate to small planets, while it is difficult to see how all of these characteristics can be found in derivatives from any of the alternative sources to which meteorites have been assigned, namely, volcanic action of the Moon or of the planets, explosive projection from the Sun, or individual aggregation in space. Some of the matter is fragmentary, implying surface conditions, while some of it is coarsely crystalline, implying deep-seated conditions. Some is volatile and combustible, implying the absence of high temperature throughout its whole antecedent history, while some as distinctly implies the presence of high temperature. In some meteorites the iron is segregated, while in others it is disseminated. Frequent brecciated structures imply fracturing and recementation. *Faulting and slickensides* demonstrate movements attributable to the parent body, but not to the meteorite itself. Veins imply internal transfer and redeposit of molecules. The absence of the oxidation of the iron accords with internal conditions, and also with the supposed absence of atmospheres from small planets, asteroids, and satellites. In short, every feature of the meteorites, save, of course, the external effects of fragmentation and of heating during their fall through the atmosphere, is assignable to small planetary bodies riven into fragments without great heat and, by reason of this, retaining the varied structure attained in the parent body.

As previously indicated, the disruption of a body like the Earth, the main mass of which has a temperature much above the melting point of its substances at low pressures, and which is greatly compressed within by self-gravity, would doubtless cause it to burst forth into a luminous body with perhaps some dispersive violence. The progressive stages of distortion which take origin in simple tidal protuberances and grow to greater and greater degrees of deformation and crustal fissuring, until the final stage of disruption is reached, could scarcely fail to bring some parts of the ocean into contact with some parts of the heated interior, with inevitable Krakatoan consequences. Fragments of the crust under these conditions might possibly give origin to meteorites, but the probabilities of such fragments being projected beyond the 640,000 miles of the Earth's dominant influence, or beyond the similar spheres of influence of other massive planets, would not seem to be great; and, if realized, the fragments would doubtless be reduced to dust, as in the case of the Krakatoan explosion, and this state of minute division would exclude such meteorites from recognition except as vanishing shooting stars. The probabilities are that the matter of a disrupted Earth or a similar massive planet would be again assembled into a planetary body by its strong self-gravity. The phenomenon would therefore be that of a temporary star. Assuming considerable dispersion, it might be rather brilliant for a time, but would rapidly cool as the result of such dispersion, and soon sink into invisibility. In the case of such a body as *Jupiter*, accepting current doctrine as to his nature, the initial brilliancy must be much greater and the cooling to invisibility much more prolonged.[1] To phenomena of this class may perhaps be tentatively assigned certain of the temporary stars. Obviously these can only be such as had no prior visibility, and such as sink sooner or later again into invisibility. Whether this invisibility were due to the superficial cooling of the nucleus, or merely to a deep enshrouding of cooled vapor, would be immaterial.

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[1] Such a body as *Jupiter* might perhaps, under proper conditions, be dispersed in the same manner as a sun as sketched beyond.

It has already been indicated that a possible result of the serious disturbance of one solar system by the near transit of another would be a fall of some of the disturbed planets upon one of the suns. This also might be an ulterior rather than an immediate result, through the modifying effects of other planets, as well as the direct effects of the primary disturbance. Such a fall must be presumed to give rise to a notable increase of heat in the central body, as well as to mechanical effects, both of which would be conditioned by the mass and velocity of the secondary. An outburst of greater or less brilliancy must be presumed to be the result. The mechanical effects upon the Sun would probably involve great changes in temporary density and condition, as well as outshoots of hot gases in various directions at high velocities. The effects might thus coincide with the phenomena of that class of the temporary stars in which a luminous state precedes and follows the outburst, and in which varying densities or high velocities in opposite directions seem to attend the temporary brilliant stage.

The disruption of suns has been neglected thus far. While, under the terms of the hypothesis, the disruption of these bodies must be rarer events than the fragmentation of the more numerous small bodies, the results must be correspondingly more important, by reason of their magnitude and character.

It has already been observed, in passing, that the internal elasticity of large hot bodies under great self-gravitative compression may so far aid in disruption, by coöperation with the differential gravity of an adjacent body, as to cause dispersion even before the Roche limit is reached. In the case of very large bodies that are already gaseous, such as the Sun, this phenomenon gives rise to a special case of extreme interest. Under this special case, there arise a large variety of particular instances due to the varying sizes, velocities, paths, rotations, and constitutions of the couplets of stars concerned, and also to the adventitious effects of their secondaries; but, for a simple illustrative case, let it be assumed that two bodies of equal masses and equal velocities are approaching each other on parabolic paths, and that at periastron they will pass through each other's spheres of disruption, or rather, spheres of dispersion. For convenience, let if be assumed that one of these bodies (*A*, Fig. 1) is gaseous, while the other (*B*) has already become so cold and solid as to act essentially as a unit, though disrupted. The history of the dispersion of the gaseous body may then be followed alone. Let the rate of rotation of the gaseous body (*A*) be relatively low, as in the case of our Sun. It may then be neglected in a general discussion, since as a dynamic factor it is trivial compared with the enormous energies of momentum and of elastic dispersion involved. This will appear clear in the outcome. Furthermore, the direction of rotation with reference to the parabolic paths might happen to be any one of an indefinite number, in many of which the effect would be inconsequential, even if the energy were large. In the close approach of these two bodies the two great dynamic factors of special interest are (1) the tidal distortion, and (2) the elastic expansion of the gaseous body.

While the two bodies are yet distant from each other, they must begin to take on elongation of the tidal type as the result of their mutual differential attraction, this elongation being aided by the high internal mobility and elasticity of the gaseous body. As the bodies approach periastron, this elongation must progress at an accelerated rate. At the moment of the entrance of the gaseous body *A* upon the Roche sphere of the body *B*, self-gravitation, in accordance with Roche's doctrine, will have been completely neutralized on the lines joining the centers of *A* and *B*, and its restraining influence upon the elasticity of the gaseous body on these lines will have been removed, while the gravitative constraint in the transverse section will be increased. The expansive energy of the compressed gaseous matter will therefore be left to exert its full projectile force in the direction of the axis of elongation. While I am unable to offer a numerical estimate of the magnitude of this expansional energy in such a body as the Sun, it is certainly of a high order of magnitude. The speed at which prominences are projected from the Sun under present conditions closely approximates to the parabolic velocity with respect to the Sun, and this is accomplished in spite of gravitation and a resisting atmosphere.

The case in hand, therefore, starts with simple tidal elongation at a distance, and increases to an explosive maximum as the bodies approach periastron. This increase is at first gradual, but in the last stages of approach to periastron the acceleration is exceedingly rapid. In any attempt to follow the process in more detail, adhering to the recognized principles of tidal action, four particulars are of special moment: (1) the progressive elongation of the body, (2) the change in the direction of tidal distortion, (3) the lag of the line of maximum elongation behind the line of maximum attraction, and (4) the rotatory effects arising from the gravitation of *B* on the tidal protuberances of *A*, which in this case will be peculiarly effective because of the enormous distortion of *A* and the very close proximity of *B* at the critical stages. The principles from which these effects arise are thoroughly demonstrated and are familiar to all students of tidal phenomena, and it is only their special applications to this case that need be discussed. The rotatory effects are a little peculiar in that both of the tidally acting bodies are rapidly approaching each other, and developing extraordinarily powerful differential attractions, while at the same time they are swinging about their common center of gravity. Near periastron they may be regarded as performing a semi-revolution about each other. By the terms of the special case in hand, this semi-revolution must be performed in a very few hours. During these few hours the gaseous body (*A*) is undergoing elongation at a rate not much less than that represented by its full explosive competency. The rotational forces are diagrammatically illustrated in Fig. 1, in which the lag is merely estimated and the distortion of *A* is simplified while that of *B* is neglected.

It is assumed that the lag of the axis of elongation of *A* is such that the effective path of explosive projection will be directed to the rear of *B*. It must be noticed that if the center of *A* passes through the outer part of the Roche sphere of *B*, the nearest edge of *A*, if undistorted, would pass within two or three hundred thousand miles of *B*, and hence that the projective elongation of *A* must pass critically near *B*; but the relative

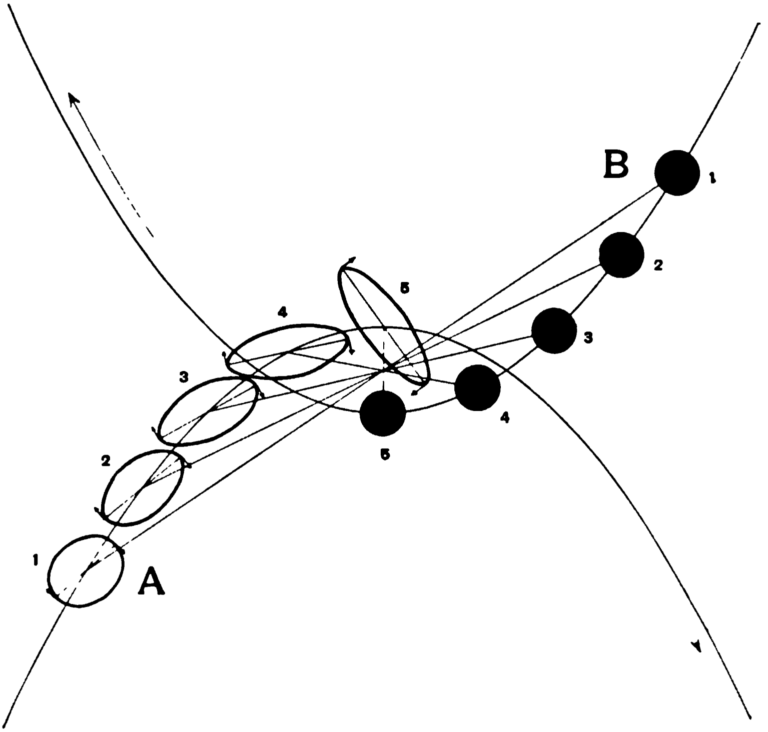


FIG. 1.— Diagram illustrating the elongating and rotatory effects of a solid stellar body, *B*, upon a gaseous sun, *A*, during their mutual approach to periastron. $A^{1, 2, 3, 4, 5}$ indicate successive positions, changes of form, and rotation of the gaseous star on its approach to periastron. $B^{1, 2, 3, 4, 5}$ represent the successive positions of a solid body of equal mass and velocity which is assumed for convenience to remain intact. Position A^1 corresponds to B^1, A^2 to B^2, etc. The lines joining their centers indicate the successive directions of mutual attraction. The arrows indicate direction of movement.

speed of the bodies A and B is so great—both being near the parabolic velocity with respect to the other—that the projected matter of A can only collide with B on the supposition that the velocity of projection at least equals the parabolic velocity of the body and acts instantaneously, the last of which is impossible. This is based on the assumption that the transverse component of the attraction of B prevents the elongation of the minor axis of A, which is true of liquid bodies tidally affected, but might perhaps break down in a gaseous body under these extraordinary conditions. The point, however, is not important here, for if the edge of the projected part of A collide with B, it will only intensify the rotatory effects under consideration, and such collision is contemplated as an essential feature of the next following case, but is excluded here as the effects of *approach without collision* is the special theme under discussion.

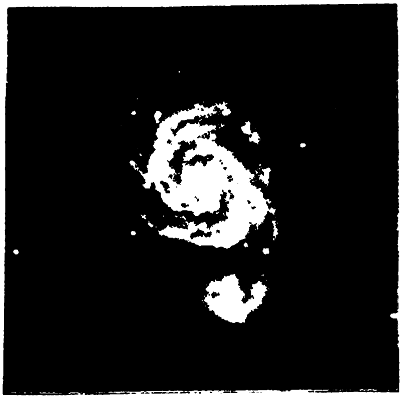
The very close approach of the elongated extremity of A to B obviously gives great effectiveness to the rotatory influence of B's attraction upon it. If the amount of this attraction be represented by the fall of $\frac{1}{1000}$ part of the mass of A toward B at a mean distance of 200,000 miles from B's surface—the masses of A and B being each equal to that of the Sun—such a fall for about two hours and a half would generate a momentum equal to the whole revolutionary and rotatory momentum of the present solar system. It would appear, therefore, that under the conditions postulated a rotation of a highly effective kind must be imparted to the elongated body. It will now appear that the previous rotatory energy of the Sun, which is only about 2 per cent. that of the solar system, is a negligible factor.

The history of A then takes this form: (1) A very rapid elongation in the hour or two preceding its entrance upon the Roche sphere. (2) After entrance upon the Roche sphere, an explosive elongation actuated by the elastic energy then remaining in the body unrestrained by self-gravity in the axis of elongation. (A portion of the original elastic energy had been consumed in the previous elongation and a corresponding amount of momentum had been acquired, the larger component of which would be effective along the changed line of elongation.) (3) After passing out of the Roche sphere, the restraints of gravity begin again to be felt and rapidly increase as *A* and *B* retire from each other, but the distance to which the extremities of *A* have already been projected, and the new relations thereby assumed to the remaining mass of *A*, and to *B*, render the renewed gravitative influence far less effective than the original, and the projection must continue until the momentum acquired is overcome. (4) Coincident with this projection a constantly increasing rotation toward *B* has been generated, which possibly reached an effectiveness comparable to that of the solar system. *The effects of explosive projection combined with concurrent rotation must obviously give rise to a spiral form.*

It seems clear from the nature of the case that there would be a certain brief period when the climax of projective effects would be reached, and that a stream of material of much greater mass and velocity than at other instants would at this time be projected from the extremities of the elongated mass in both directions. There should therefore be two chief arms to the resulting spiral starting from the opposite points of the central mass and extending outward to the limits of the spiral—indeed constituting the most outlying portions of the spiral. These must be curved in a common direction by the rotation of the mass. Such predominant arms are notable features in the typical spiral nebulæ. They are well shown in Nos. 1, 2, 3, 4, 5, and 6, Plate II, all of which are reproductions from photographs furnished by the late Professor Keeler.

In the illustrative case that has just been discussed the solid body *B* was made to represent a convenient possible case but one whose real frequency is quite unknown, since extinct suns are beyond the reach of observation. If the active lives of suns are no greater than the periods deduced from computations founded on the Helmholtz theory of solar heat, extinct suns should either be numerous, or the whole previous history of the stellar system must have been short; or else, as a *tertium quid*, some effective means of regeneration must be assumed.

PLATE II



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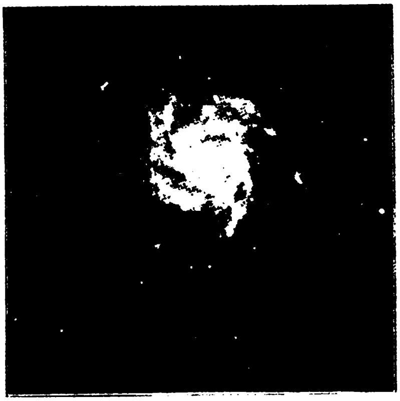

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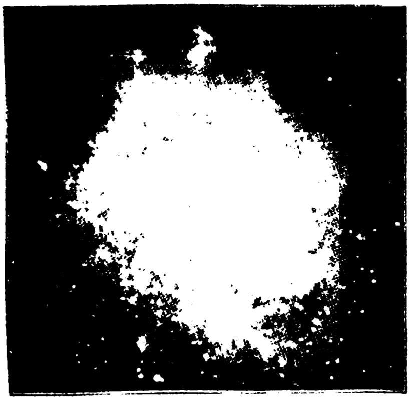

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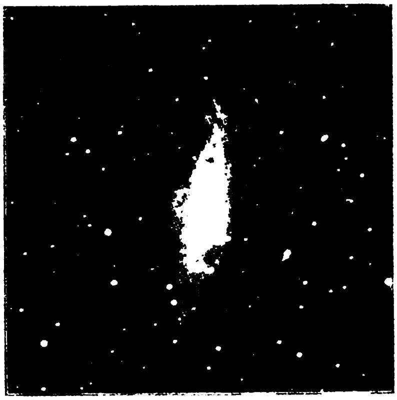


6

SPIRAL NEBULAE

1. *M 51 Can. Ven.* = *G. C. 3572–3574*
2. *M 101 Urs. Maj.* = *G. C. 3770–3771*
3. *M 74 Piscium* = *G. C. 372*
4. *H IV 76 Cephei* = *G. C. 4594*
5. *H 33 Trianguli* = *G. C. 352*
6. *H I 53 Pegasi* and her nebula

In the more typical case of two live suns coming into such close relations, its seems probable that mutual dispersion might follow without serious collision, since the analysis of the phenomena seems to show that the mutual elongations of the live suns would develop on essentially parallel lines whose constant shiftings would be mutually consonant, as illustrated in Fig. 2. If no serious contacts were developed, the two resulting spirals would separate and pursue the paths normal to their parent stars, with such modifications as may have resulted

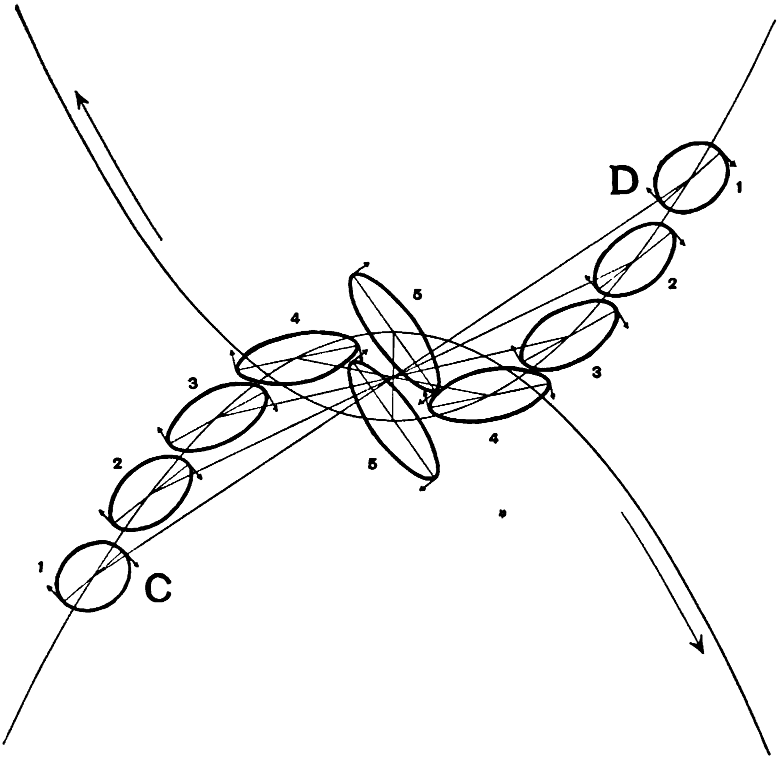


FIG. 2.—Diagram illustrating the progressive elongation and rotation of two suns, *C* and *D*, approaching perihelion. The position C^1 corresponds to D^1, C^2 to D^2, etc.; the lines joining these indicate the successive directions of mutual gravitation, and the arrows indicate direction of movement. The progressive elongation, the lag, and the rotation of the bodies at successive stages are diagrammatically indicated.

from the loss of energy involved in giving rotation to the nebulæ.

If, however, the periastron approach is so close that partial collision ensues, the analysis seems to indicate that the elongated bodies which would be developed previous to contact would not collide end to end centrally, but by a lateral shear, as illustrated in Fig. 3. In this case the arrested momentum combines with mutual attraction to give a rotatory movement of the highest order, and the heat and the resilience from impact must combine to intensify the dispersive competency. The arrest of momentum

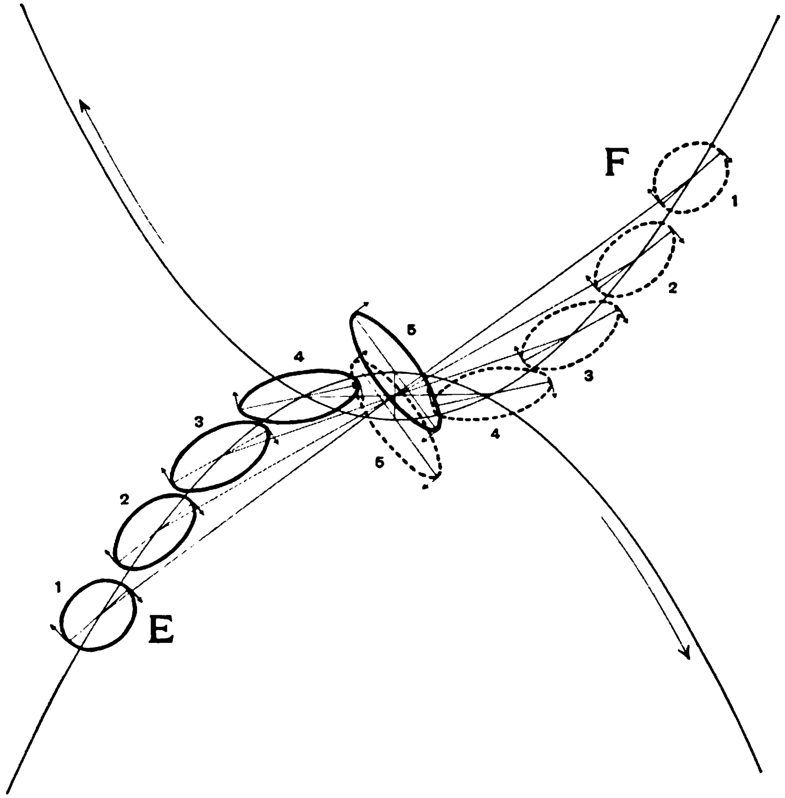


FIG. 3.—Diagram illustrating the same phenomena as Fig. 2, save that the periastron distance is so small that the bodies collide by a shearing stroke.

may be presumed to go so far in some cases as to cause the two bodies to unite to form a single spiral nebula of the largest and most dispersed order, such perhaps as the well-known great spiral nebulæ; or the arrest may be partial, and certain parts of one or the other, or both, of the masses may escape. In No. 1, Plate II, we seem to have a possible example of this, in which the escaping, or partially escaping, mass[1] is still associated with the longest arm of the spiral.

In case the collision of two suns becomes essentially central, a general dispersion of the most violent sort may be inferred to follow, and this may find exemplification in the vast irregular nebulæ, which are in many cases more or less radiant, and in some cases consist of two irregular masses which perhaps represent the wrecked originals. The collision of dead suns in which disruption shortly preceded actual impact may also play a part in forming irregular nebulæ.

Speculation may perhaps go so far as to attribute ring nebulæ to the central penetration of a concentrated solid body through a gaseous mass.

It is as impossible as it is unnecessary to consider here the infinite variety of sub-cases which the hypothesis under consideration involves, but it seems advisable to note that the case of equal suns with equal velocities, which has been used in illustration, is not the most prevalent case; for inequality of mass and momentum is quite certainly the rule, rather than equality or sub-equality. Where one of the suns is much smaller than the other, the dispersive influence will be most largely felt by it, and so it seems probable that there may be a series of cases in which the minor members of the couplets are dispersed with different intensities into complete nebulæ while the major members only suffer varying degrees of eruptive action or partial conversion into nebulæ and so perhaps become stars with nebulous adjuncts or atmospheres. Under this conception small nebulæ should be much more numerous than large ones. If

[1] This is assumed to have been a dead sun because of the limited evidence of explosive action.

large hot planets, such as Jupiter is supposed to be, are potentially gaseous, and if by disturbing approaches of stellar systems such planets are thrown out of their allegiance to their primary suns and take on comet-like courses, they would be specially liable to disruption and dispersion into small nebulæ, and would augment the number of the latter.

Whether the existing stellar movements and the mutual attractions of the stars are such as to give any substantial ground for believing that close approach can be a *chief* agency in producing comets, meteorites, and nebulæ, can only be determined when some approximate knowledge of the dispersion, the masses, the velocities, and the paths of the stars is gained. If the stars be considered simply as so many scattered bodies flying through space in straight lines at computed rates, and all mutual attractions and systematic relations be ignored, the frequency of disturbing approaches would not seem to be great and the quantitative value of the doctrine here sketched would seem to be questionable. The solar system has certainly never been subjected to disturbing approach since its present organization. But the assumptions made are certainly not the true ones and may not be representative. Besides the mere hazard of flying bodies, the mutual attraction of two stars after they enter upon each other's spheres of dominant influence — and these are very large — increases notably the probabilities of a disturbing approach even in the case of stars moving in opposed directions, while in the case of stars moving in sub-parallel and gently converging paths at sub-equal velocities, it may apparently become a dominant factor. At the average computed distances of the stars from each other, their mutual attractions are very slight, and in the central portion of the stellar system, in which the Sun seems to be placed at present, the general attractions are probably nearly balanced. Two stars, therefore, whose speeds are sub-equal and whose paths gently converge, may be controlled almost freely by their mutual attractions after they come within the spheres of each other's dominant influence. Such stars under mutual control would describe paths relative to each other similar to those assumed in the discussion. Their closeness of approach at periastron would be determined by the *relative differences* (not the total amounts) of their speeds and momenta. The principle of sub-parallel movements applies here and gives results quite at variance with those that obtain in cases of opposed movements, where the *relative sums* of the velocities and momenta are to be considered. The movements of the long-orbit comets seem to be concrete expressions of this principle, as their perihelia are largely clustered on the front side of the Sun, *i. e.*, the side toward which it is moving, and they make close approaches to it. Such star clusters as the *Pleiades*, the members of which seem to have proper movements nearly the same in amount and direction, are doubtless also expressions of the principle of sub-parallelism, and in their remarkable nebulosity they may at the same time illustrate the doctrine of disturbed secondaries leading on to dispersive action, a part of the product of which remains associated with the stars themselves, while a part is more or less widely scattered, as the terms of the doctrine require.

If our stellar system has a definite boundary and is a flattened spheroidal cluster or a discoid, and if the ideal paths of the stars are elongate orbits stretching from border to border across the heart of the cluster (except as diverted by close approaches), then the orbital speeds and momenta should be lowest on the outer surface, and the paths should there be most frequently sub-parallel, and hence the conditions for the close approach of two suns through their reciprocal attraction be there most favorable. Now, visible nebulæ are most frequent in the regions polar to the Milky Way, and they may be regarded as lying on the flat sides or outer border of the stellar discoid where these conditions of low orbital velocity and momenta and prevalent sub-parallelism are dominant, and thus the distribution of nebulæ and the doctrine of close approach seem to be, so far at least, brought into harmony.

It may be needless to remark that the general conception lying back of the doctrine of dispersion by close approach has a complementary regenerative or reconstructive phase, which, taken with the dispersive phase, makes up a cyclic process. With the disruptive action there is correlated a reciprocal concentrative action, which is supposed to reproduce organized systems out of the wreckage of disrupted systems. The notion is further entertained that the two processes may be mutually self-adjustable, within the limits of general conditions, and thus may give a large degree of perpetuity to the existing phase of the stellar system.

University of Chicago,
June 1901.

THE SHIFT OF THE CADMIUM LINE OF WAVE-LENGTH 4800 DUE TO PRESSURE.

By WILLIAM B. HUFF.

SEVERAL years ago Humphreys and Mohler, working in this laboratory, carried out a research on the pressure shift of the lines of the arc spectrum. Their results indicated a linear relation between the pressure and the shift. From a study of the lines due to substances contained in the poles as impurities, they also concluded that the shift was independent of the amount of material present; that is, that it was a function of the total pressure to which the arc was subjected rather than of the density of the vapor of the substance whose lines were being studied. It has also been found by Mr. L. E. Jewell that at atmospheric pressure the spectrum lines show a shift due to the presence of a large amount of the given material in the arc.

At the beginning of the present year, Professor Ames suggested to the writer a further study of the pressure shift of metallic lines, using alloys of various compositions. The shifts for a given metal used as a constituent of an alloy could be compared with those obtained when the metal alone was used. The results could then be examined as to possible effect of the amount of metal present and also for the effect due to the second metal of the alloy.

The apparatus employed was essentially that used by Humphreys and Mohler. The arc was in a heavy iron cylinder. The 21-foot concave grating gave a dispersion of about 1 mm to the Ångström unit in the second order. The camera was supplied with a shutter, so arranged that the center of the plate could be exposed to the spectrum as obtained under pressure. A second exposure gave the lines, at atmospheric pressure, above and below the first set.

It was necessary first of all to study the changes in lines which are produced by varying the amount of material in the arc. Ordinary carbon poles contained so much sodium that the D lines were strong and bright when light from near the negative pole was brought on the slit. They reversed and the width of the reversal increased as the light was taken from points nearer the positive pole. Under pressure, the arc passes only when the poles are close together. This short arc, at atmospheric pressure, gave the D lines black on otherwise uniformly bright continuous spectrum. Their edges were as sharp as in the solar spectrum. A position of the image of the arc on the slit could easily be found for which D_1 was bright while D_2 remained black. A large amount of a sodium salt added to the arc caused the lines to broaden, until for a long arc they came together, the edges being very hazy. For a short arc they were somewhat sharper, owing to the effect of the continuous spectrum.

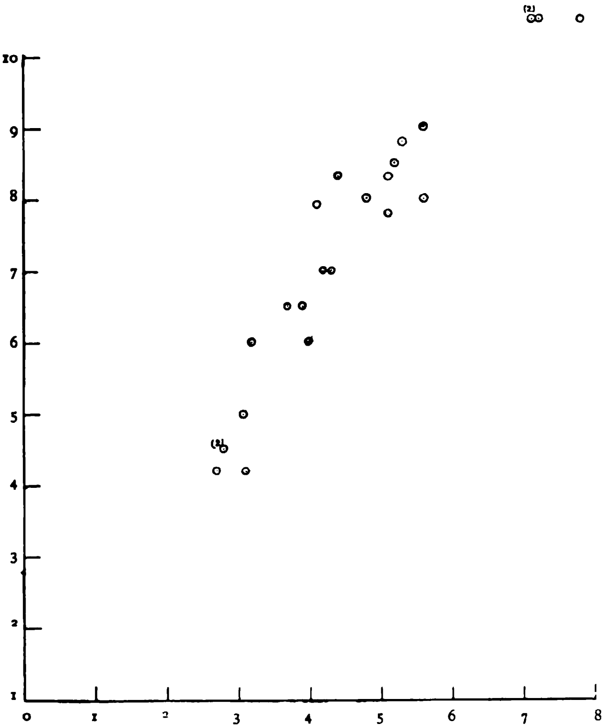
This great broadening was obtained for lines from other metals, but in no other case was a clean, black line obtained on a uniform, bright background.

An asymmetrical broadening was often noted, *e. g.*, the potassium lines in the green. In the cases observed, anything like accurate settings to measure shift would have been difficult, even using the reversal as the center of the line.

Using cadmium in a carbon pole, it was found that for amounts sufficient to give the lines in the blue heavy and broad, these lines remained symmetrical and were not broadened toward the red. It was decided therefore to study the cadmium lines λ 4800 as obtained from pure cadmium and also from an alloy of cadmium and zinc and one of cadmium and lead; the first pair being much alike chemically as well as spectroscopically, and the second having nearly equal melting points. The alloys were made by fusing the metals together in a porcelain crucible, special care being taken to secure uniform composition.

When the alloy formed one pole of the arc, a large amount of vapor was formed, and this in a few seconds reduced the transmitted light to a dull, red, glow, entirely wanting in the shorter wave-lengths.

The best results were obtained by using carbon poles bored to a depth of about 2 cm and containing a small amount of alloy. It was found that 1 per cent. of cadmium in zinc gave the cadmium lines strong enough to photograph readily. They remained sharp, even under pressure, and the intensity was nearly uniform throughout the series of exposures, two at atmospheric pressure and an intermediate one for pressure shift. In the alloy with lead somewhat more cadmium was necessary.



Ordinates: pressure; 1 unit = 1 atmos.
Abscissae: shift; 1 unit = 0.01 Å. U.

Fig. 1.

The presence of considerable continuous spectrum was effective in keeping the edges of the lines sharp. Except for very short arcs, the metallic vapors cut out completely the carbon bands. This was particularly noticeable in the case of lead. A similar effect due to zirconium has been pointed out by Professor Rowland.

A large number of plates were taken before any of them were measured. The plates were taken in no special order. Needless to say, the greatest care was taken to prevent accidental disturbances. Of the large number of plates taken, many were found to be faulty in several particulars and were rejected without being measured. None was thrown out merely because it showed an unexpected shift. The measurements were completed before any attempt was made to classify shifts or to plot curves. In all, more than forty plates were measured. The general results fall into two classes: shifts comparatively regular, though not increasing linearly with the pressure; and shifts which are decidedly erratic. For the first class a comparatively large amount of cadmium was used in the carbon pole. For the second group the cadmium in the arc was but a small part of the alloy present.

The tables give an idea of the order of agreement shown by the results. The pressures were indicated by a gauge, calibrated with a mercury column.

It is when the pressures and the corresponding shifts are plotted that the difference between the two sets of plates comes out most clearly. Cadmium alone, or in an alloy with but a small percentage of another metal, gives a series of points

PRESSURE SHIFT OF CADMIUM λ 4800.

Cadmium in arc.

Pressure.	Shift × 10^2	Pressure.	Shift × 10^2
4.5 atmos.	2.8 Å. U.	7.9 atmos.	4.1 Å. U.
4.5	2.8	7.8	5.1
4.9	3.1	8.3	4.4
6.5	3.9	8.3	5.1
6.5	3.7	8.8	5.3
7.0	4.2	9.0	5.6
7.0	4.3		

Alloy of cadmium + not more than 2% zinc.

Pressure.	Shift × 10^2	Pressure.	Shift × 10^2
4.2 atmos.	3.1 Å. U.	8.5 atmos	5.2 Å. U.
4.2	2.7	10.5	7.1
6.0	4.0	10.5	7.1
6.0	3.2	10.5	7.2
8.0	5.6	10.5	7.8
8.0	4.8		

Alloy of zinc + 2% cadmium.

Pressure.	Shift × 10^2	Pressure.	Shift × 10^2
6.0 atmos.	3.0 Å. U.	8.5 atmos.	5.1 Å. U.
6.3	6.2	8.8	5.7
7.0	4.3	9.0	6.7
7.0	4.8	9.0	9.1
8.5	5.0		

2 % cadmium in lead..

Pressure.	Shift × 10^2	Pressure.	Shift × 10^2
4.2 atmos.	1.0 Å. U.	6.0 atmos.	6.1 Å. U.
4.2	3.2	6.0	3.9
4.2	0.5	8.0	4.1
4.2	2.3	8.3	6.0
6.0	6.2	8.5	5.3

which are fairly regular and which seem to indicate that the relation between pressure and shift is nearly, but not exactly, a linear one (Fig. 1).

Weighting these values for the shift according to the reliability of the plate for measurement, and taking means for pressures approximately the same, the following ten points are obtained and used to determine a mean curve (Fig. 2).

No. Plates.	Pressure.	Shift × 10^2.
2	4.2 atmos.	2.8 Å. U.
2	4.5	2.8
1	5.0	3.1
2	6.0	3.6
2	6.5	3.8
5	7.9	4.7
2	8.3	4.9
1	8.5	5.2
1	8.8	5.3
4	10.5	7.2

This resultant curve does not pass exactly through the point (0,1) corresponding to zero shift at atmospheric pressure. This may indicate experimental errors, or it may be due to a shift arising from varying amounts of metal present in the arc. The possibility of error is too great to admit of any definite statement as to this question, since it is just here that accidental disturbances would most seriously affect results. Suffice it to say that while the lower part of the curve is nearly a right line, with increasing pressure, the resulting shift becomes proportionally greater and the curve clearly becomes concave to the pressure axis.

The second group of plates shows the pressure shift when but little cadmium was used with a large amount of lead or of zinc. The pressures with corresponding shifts are shown in Fig. 3. It is impossible to determine any curve from the points laid down, yet the lines which gave these results are fully as clean and fine, and in all ways appear as reliable as do those of the first set. The results for the cadmium-lead alloy show a variation which seems attributable to the presence of the lead. The results for the cadmium-zinc show rather more regularity, but here, too, there seems to be more variation than cadmium alone shows.

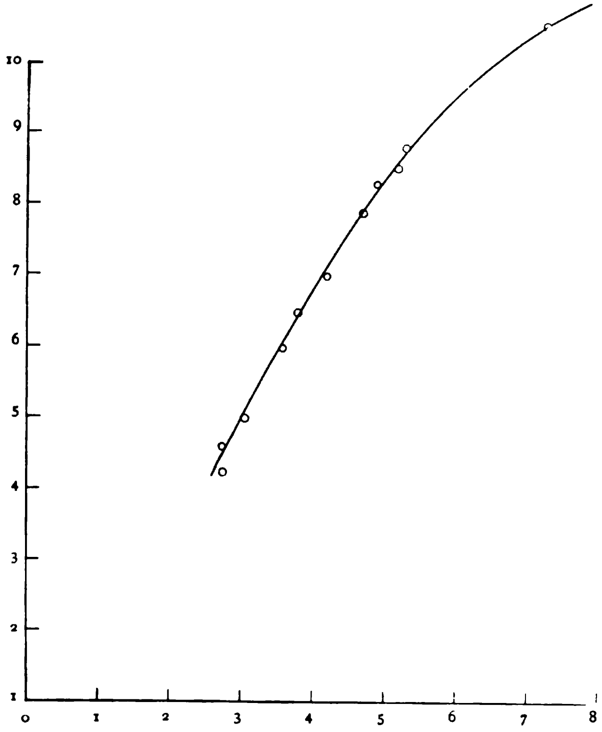


FIG. 2.

In work of this character accidental disturbances are very serious and effectually prevent more than approximate agreement in results. Giving a double exposure for the spectrum at ordinary pressure would enable one to detect an accidental displacement of the camera only when sharp and fine lines are being studied. For heavier lines (all others are usually cut out by the metals present) a second exposure for only a part of the length of the ordinary line gives an effective test for accidental displacement.

Another possibility of serious error arose from the longer exposures necessary when but a small percentage of cadmium was used. It is difficult to say exactly how long the exposures were, but they usually lasted from half a minute to a minute. The accumulation of vapors gradually shut off the light, and the arc was continually going out. During such an exposure, the heating would raise the pressure as much as an atmosphere. The one recorded is the mean of the initial and final pressures. The fact that the metal was below the end of the carbon pole made it necessary to allow a little time for vaporization to begin before the pressure was noted.

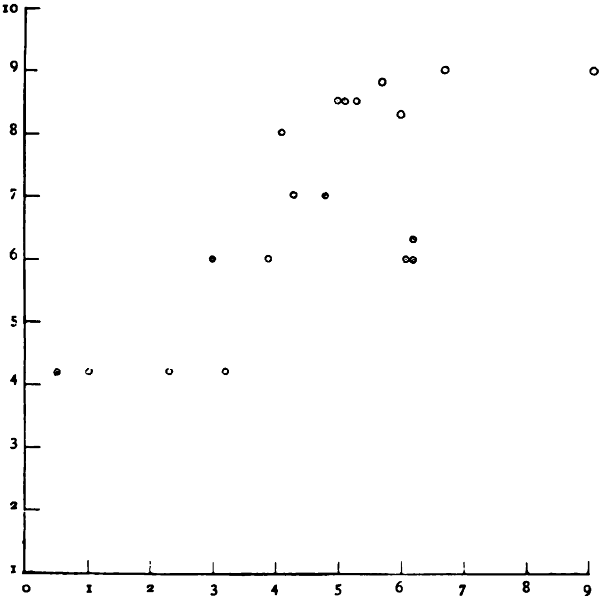


Fig. 3.

In the plates from the arc containing but a small percentage of cadmium a longer exposure was necessary, and the lines of the other metal of the alloy were usually strongly reversed. It was hoped to use zinc λ 4812 as a check on the cadmium shift, but the zinc line was so heavy that definite measurements on it were impossible. It can be said, however, that the results of the measurements attempted differed quite independently of the cadmium lines.

The cadmium line was generally found not broadened. When the vaporization took place very rapidly, the line usually became hazy and broadened to the red. Despite the tendency to haziness and reversal shown by lines under pressure, many plates were obtained showing sharp, clean, lines. In no case are the measurements of a shift of a reversed line given. The question as to whether the shift of a sharp line is the same as that of one which is reversed seems not yet to have been settled.

The general results, therefore, from the two groups of plates go to show that the amount of a metal present does affect the pressure shift. The further fact that some of the best plates obtained were from the alloy of cadmium and lead and that these show wide variation indicates that the presence of a second metal is not without an effect.

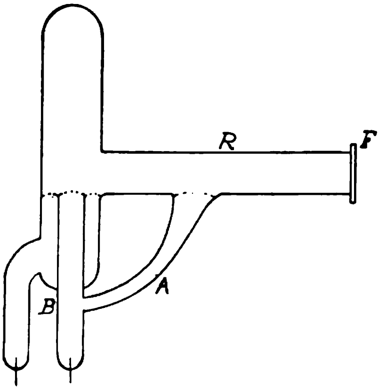
Finally, the relation of pressure and shift is not a linear one.

PHYSICAL LABORATORY,
JOHNS HOPKINS UNIVERSITY,
June 1901.

ON THE COMPOUND TRIPLETS IN THE LINE SPECTRUM OF MERCURY.

By C. RUNGE and F. PASCHEN.

IN an article published in 1893, J. R. Rydberg[1] deals with the compound triplets of the first secondary series in the spectra of calcium, strontium, zink, cadmium, and mercury. These triplets do not merely consist of three single lines, but each of the three components is accompanied by weaker satellites whose distances follow certain laws that Rydberg has found. He then remarks that, as far as the observations of Kayser and Runge show, the compound triplets in the spectrum of mercury do not fall into the same order as the corresponding lines of the other elements, and he comes to the conclusion that Kayser and Runge's observations are probably incomplete and require revision. In an investigation, not yet completed, on the radiation of light in a magnetic field, the authors have studied the light of vacuum tubes with mercury electrodes[2] and the light of an Arons mercury lamp in a form not unlike the one used by Perot and Fabry. This lamp had the above arrangement:



It differs from Perot and Fabry's arrangement in the tube *R*, which is closed by a quartz window *F* and communicates with the tube *B* through the tube *A*. This tube serves to keep the level of the mercury in *B* near the mouth and at the same time to lead the mercury which condenses in *R* back to *B*. The lamps can be run for an hour without cooling.

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[1] *Wied. Ann.*, 50, 625, 1893; and *Öfversigt af kongl. Vetenskaps Akademiens Förhandlingar*, 1893. No. 8, Stockholm.

[2] Of the form invented and described by F. PASCHEN. *Physikal. Zeitschrift*, 1, 478, 1900.

On analyzing this light by means of a large Rowland grating we found, indeed, that the observations of Kayser and Runge have to be supplemented by a few lines of lesser intensity. The wave-lengths of these lines were either interpolated between the wave-lengths measured by Kayser and Runge or determined by means of one of the wave-lengths of these observers and the wave-lengths of its ghosts. A more accurate determination would have to take account of the fact that the lines here given as single probably all consist of several components. In the higher orders of the Rowland grating distinct traces of the components are to be seen; but the dispersion is not quite sufficient to measure them satisfactorily. With the supplementary lines found by the authors the two compound triplets observed consist of the following components :

λ	$\frac{1}{\lambda}$	λ Kayser & Runge	λ	$\frac{1}{\lambda}$	λ Kayser & Runge
3663.46	27296.60	3663.25	3027.66	33028.81	3027.62
3663.05[1]	27299.65		3025 79	33049.22	....
3655.00	27359.78	3654.94	3023.64	33072.72	3023.71
3650.31	27394.93	3650.31	3021.68	33094.17	3021.64
3131.95	31928.99	3131.94	2655.29	37660.67	2655.29
3131.66	31931.95	3131.68	2653.86	32680.96	2653.89
3125.78	31992.01	3125.78	2652.22	37704.27	2652.20
2967.64	33696.81	....	2536.12	39430.31	....
2967.37	33699.87	2967.37	2534.89	39449.45	2534.89

Writing the wave numbers $\frac{1}{\lambda}$ in the way in which Rydberg shows the arrangement of the compound triplets, we obtain the table on opposite page.

The difference between the first and second column of wave numbers and the difference between the second and third column are in accordance with the corresponding differences in the triplets of the second secondary series, as far as the accuracy of the determinations goes. With the supplementary lines found by the authors the compound triplets in the spectrum of mercury closely resemble the compound triplets in the spectra of calcium, strontium, zinc, cadmium. There is, however, this difference, that in the spectrum of mercury there is one satellite more to each main line. Rydberg suggests that there is in all compound triplets an infinite number of satellites to each main line, of which only a few are strong enough to be observed.

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[1] This line has also been observed by W. B. HUFF, though not measured. ASTROPHYSICAL JOURNAL, 12, 108, 1900.

Wave numbers	Difference	Wave numbers	Difference	Wave numbers
27,296.60	4632.39	31,928.99	1767,82	33,696.81
Diff.: 3.05		Diff.: 2.96		Diff.: 3.06
27,299.65	4632.30	31,931.95	1767.92	33,699.87
Diff.: 60.13		Diff.: 60.06		
27,359.78	4632.23	31,992.01		
Diff.: 35.15				
27,394.93				
33,028.81	4631.86	37,660.67	1769.64	39,430.31
Diff.: 20.41		Diff.: 20.29		Diff.: 19.14
33,049.22	4631.74	37,680.96	1768.92	39,449.45
Diff.: 23.50		Diff.: 23.31		
33,072.72	4631.55	37,704.27		
Diff.: 21.45				
33,094.17				

The relative intensities of the radiations whose wave numbers appear in a horizontal line in the table given above are by no means the same in the different horizontal lines. The radiation, for instance, corresponding to the wave number 27,299.65 is much weaker relatively to 31,931.95, than 27,296.60 to 31,928.99 or 27,359.78 to 31,992.01.

But the radiations corresponding to one another in the two compound triplets have the same relative intensities.

HANNOVER,
June 1901.

THE MOTION OF *POLARIS* IN THE LINE OF SIGHT.[1]

By J. HARTMANN.

AT the third conference of astronomers and astrophysicists, held at Williams Bay, Campbell made, on September 8, 1899, the interesting announcement that he had succeeded in spectroscopically resolving the Pole-star, *α Ursae Minoris*, into a system of at least three bodies. He published the data of observation which led to the discovery in the ASTROPHYSICAL JOURNAL (**10**, 180, 1899), and somewhat more extensively in the *Publications of the Astronomical Society of the Pacific* (**11**, 195, 1899). Campbell's observations showed that the visible star *α Ursae Minoris* has a variable motion in the line of sight, moving about the center of gravity common to itself and the invisible body in a period of $3^d\ 23^h\ 15^m$. The amplitude of this motion is very slight, the maximum velocity amounting to only ±3 km. The motion of the center of gravity of this system is not, however, constant, but slowly variable, compelling the assumption of a third body. As the latter motion has a still unknown period of many years, I beg to designate it as the secular motion to distinguish it from the motion of short period.

At the time of this discovery the great photographic refractor of the Astrophysical Observatory had just been mounted, and the first plates with the new spectrograph (No. III) attached to it could be taken in February 1900. Since the short period variations in the velocity of *Polaris* are of such slight amount as to be demonstrable by only very accurate observations, this star seemed an excellent object for testing the efficiency of the new spectrograph; and this the more since the attempt had elsewhere been made in vain to confirm Campbell's valuable observations. It did, indeed, later appear that the selection of this star was unsuitable in this respect—that a series of at least five successive days of observation were essential for a wholly independent determination of the period. Under the very unfavorable weather conditions prevailing in the spring of 1900 I only succeeded in obtaining four successive days of observation. They yielded the following velocities relative to the Sun:

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[1] Translated, at the author's request, from the *Sitzungsberichte der K. Akad. zu Berlin*. Session of April 18, 1901.

1900 April 2.38	−13.8 km
3.37	−17.7
4.36	−15.3
5.42	− 9.8

These observations displayed a variation of short period, and when three further successful observations were obtained on April 23, 24, and 25, which well fitted those above, on the assumption of a four-day period, it could then be said that a confirmation of Campbell's discovery had been attained.

It became apparent in the first observations made with the new spectrograph that the plates were affected in a very marked degree by the variations in the temperature of the air. In order to remedy this difficulty the whole spectroscope was enclosed in a box of light wood, within which the temperature of the air can be automatically kept constant. These alterations in the apparatus caused an interruption of the observations until autumn, which unfortunately again brought very unfavorable weather. It was not until January 1901 that I succeeded in getting the desired number of observations for an accurate determination of the velocity curve. As this series is distant by one and a half years from Campbell's measures I shall employ it in what follows for deducing a more accurate value of the length of the period. It will then be possible to correct all previous observations for the effect of the short-period motion and in this way to obtain the data for the determination of the secular motion.

A summary of my observations is given in Table I. In order to facilitate the comparison with the results of other observers I give the epochs of the plates in Gr. M. T., as well as in Julian days, the first three figures, 241, being in all cases omitted. As I have elsewhere shown, the velocities so far derived from the plates are to be regarded as provisional on account of the lack of definitive values of the wave-lengths of the spectral lines employed. In a definitive reduction of the data, however, the individual results would be changed only by the fraction of a kilometer.

TABLE I.

Plate No.	Gr. M. T.					Julian day	V
			d	h	m	d	km
III 54	1900	Mar.	7	10	8	5086.42	− 15.1
61			9	10	30	5088.44	− 14.2
64			10	10	10	5089.42	− 13.1
66			11	7	25	5090.31	− 11.7
71			14	11	35	5093.48	− 17.1
77			21	11	50	5100.49	− 12.7
92		Apr.	2	9	0	5112.38	− 13.8
94			3	8	50	5113.37	− 17.7
101			4	8	40	5114.36	− 15.3
102			5	10	10	5115.42	− 9.8
130			23	9	40	5133.40	− 16.4
134			24	10	50	5134.45	− 13.6
135			25	8	42	5135.36	− 4.7
228		Nov.	7	8	0	5331.33	− 14.2
234			8	6	5	5332.25	− 12.8
235			8	9	0	5332.38	− 14.0
236			8	16	30	5332.69	− 12.6
237			9	5	15	5333.22	− 9.7
241		Dec.	3	9	35	5357.40	− 9.6
254*	1901	Jan.	8	5	30	5393.23	− 10.7
255			8	8	40	5393.36	− 11.5
256			9	4	39	5394.19	− 12.4
258*			9	8	56	5394.37	− 13.9
266			10	4	12	5395.18	− 17.3
269*			11	4	2	5396.17	− 13.5
272			11	9	20	5396.39	− 12.9
275			14	4	25	5399.18	− 15.4
277*			14	8	55	5399.37	− 15.9
278			15	4	20	5400.18	− 12.6
280			16	4	25	5401.18	− 9.5
284			16	9	35	5401.40	− 11.2
289			17	4	25	5402.18	− 12.0
290*			17	5	3	5402.21	− 14.7
295*			17	10	33	5402.44	− 15.3
296			18	8	30	5403.35	− 15.1

* Plates thus designated were measured for me by Mr. Hansky, of Pulkowa, who is residing in Potsdam for the purpose of familiarizing himself with spectroscopic work. Plate III 290 was exposed for only ten minutes, as a test of the light-power of the 80 cm refractor. Although well measurable, it is still somewhat too faint. Hence the result derived from it will not be used further.

The observations from the 8th to the 18th of January, 1901, show the periodic change of *V* very clearly. I have platted these in the accompanying cut, reduced to two successive revolutions, and have drawn the velocity curve, which shows great similarity to the one drawn by Campbell from his observations. Campbell also gives the descent from maximum to minimum as steeper than the ascent to maximum, although it is somewhat more strongly indicated in my measures than in his. A more extensive mass of data will be necessary to decide whether or not this change in the curve is real. The amplitude of the variation in velocity turns out to be 6.0 km, just what it was found to be by Campbell.

The following epochs may now be derived from the curve:

Maximum on 1901, January 12 = $5397^{\mathrm{d}}.48$
Minimum on 1901, January 13 = 5398.97

My remaining dates of observations are so scattered that they can contribute nothing of importance to the curve, but they are sufficient for the sure determination of the whole number of revolutions elapsed.

The observations gave:

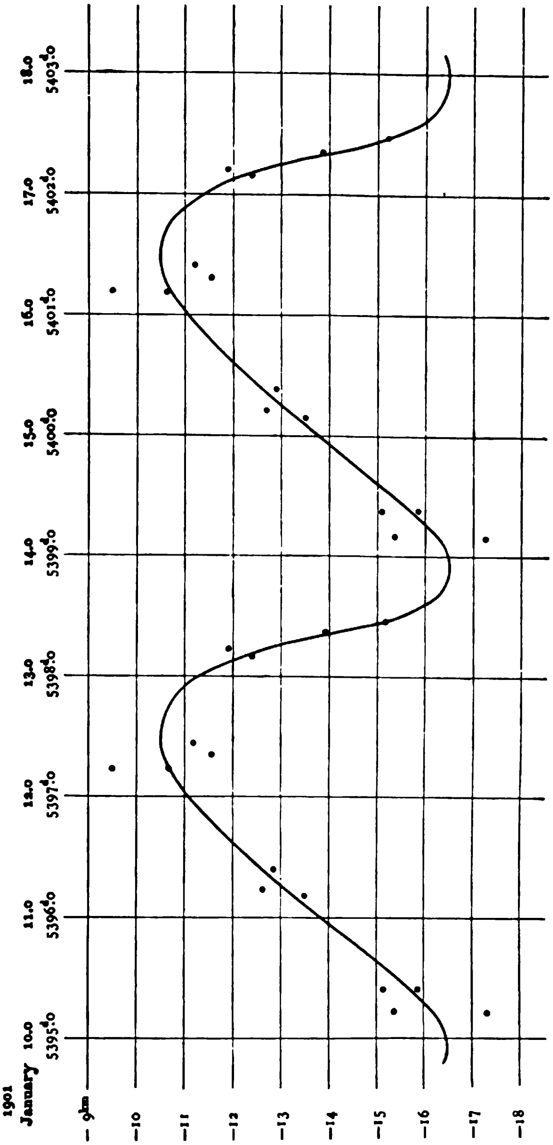
			Diff.
Maximum 1900	April 5,	$5115^{\mathrm{d}}.42$	
	Nov. 9,	5333.22	$217^{\mathrm{d}}.80 = 55\,P$
	Dec. 3,	5357.40	$24.18 = 6\,P$
1901	Jan. 12,	5397.48	$40.08 = 10\,P$
		282.06	$= 71\,P$

I have drawn a curve from Campbell's observations in 1899 which yields these epochs:

Maximum 1899 Aug. 30 = $4897^{\mathrm{d}}.29$
Minimum 1899 Sept. 1 = 4899.06

The interval from August 30, 1899, to April 5, 1900, is 218 days, corresponding to 55 revolutions. Hence there must fall $71 + 55 = 126$ periods between August 30, 1899, and January 12, 1901, whence we derive the following period P:

Maxima	Minima
$5397^{\mathrm{d}}.48$	$5398^{\mathrm{d}}.97$
4897.29	4899.06
500.19	499.91
$P = 3^{\mathrm{d}}.9698$	$P = 3^{\mathrm{d}}.9675$



VELOCITY CURVE OF *POLARIS*

The small difference between the two values is due to the displacement of the relative position of the minima with the maxima as mentioned above. We may regard the mean of these two figures, viz.:

$$P = 3^{\mathrm{d}}.9686,$$

as the true period. If we assume that the interval of 500 days employed is still uncertain by $0^{\mathrm{d}}.1$, P will be accurately determined to one five-thousandth of its value, or to $0^{\mathrm{d}}.0008$. The uncertainty does not amount to half a period, so that one could be in doubt as to the number of revolutions completed for more than 2500 revolutions or for 27 years. Campbell's observations in 1896, as well as those of Vogel in 1888, must therefore fit the curve with perfect accuracy.

Campbell's seven plates in 1896 are distributed so unfavorably that an independent velocity curve cannot be derived from them. If we apply to them Campbell's curve for 1899 these two epochs result:

Maximum 1896 Oct. 8 = $3841^{\mathrm{d}}.77$
Minimum 1896 Oct. 10 = 3843.55.

266 revolutions are thus included between the epochs given for 1896 and 1899, hence $266 + 126 = 392$ revolutions between 1896 and 1901. Therefore we have for the definitive determination of P from the interval of 1896 to 1901:

Maxima	**Minima**
$5397^{\mathrm{d}}.48$	$5398^{\mathrm{d}}.97$
3841.77	3843.55
1555.71	1555.41
$P = 3^{\mathrm{d}}.96865$	$P = 3^{\mathrm{d}}.96791$

We may regard the mean of these two figures as the definitive value of the period, whence we get[1]

$$\mathrm{P} = 3^{\mathrm{d}}.9683 = 3^{\mathrm{d}}\,23^{\mathrm{h}}\,14^{\mathrm{m}}\,21^{\mathrm{s}}.$$

[1] On account of the secular motion of the system this period is not identical with the true period of revolution of the star. To determine the latter, we must apply to P a correction $\frac{PR}{L}$, where R is the secular velocity and L the velocity of light. This small correction cannot be computed until the secular motion has been accurately investigated, and I shall therefore not discuss this until a later time. For the computations given here we do not employ the true period of revolution, but the above apparent period, which holds good for a value of R of about -14 km per sec.

If we estimate the uncertainty of the last interval employed, 1555 days, as $\pm 0^{\mathrm{d}}.25$, the uncertainty of P will be $\pm 0^{\mathrm{d}}.0006$. This period is precisely equal to that of the well-known spectroscopic binary *β Aurigae.*

The observations of Vogel and Scheiner on the velocity of *α Ursae Minoris* are based on two plates taken on November 14 and December 6, 1888. These isolated observations can contribute nothing toward a more accurate determination of the period, but they are of great value in investigating the secular motion. To determine this, we must correct the values of V for the particular dates of observation for the effect of the periodic motion. I have tabulated in Table II the values of this correction, B, with the argument A, which is the interval in days elapsed since the last preceding minimum. These corrections have been taken from a curve which equally well represents Campbell's observations and my own.

TABLE II.

A	B	A	B	A	B
d	km	d	km	d	km
0.0	+3.0	1.4	−1.0	2.8	−2.2
0.1	+2.9	1.5	−1.3	2.9	−1.7
0.2	+2.8	1.6	−1.6	3.0	−1.2
0.3	+2.6	1.7	−1.9	3.1	−0.6
0.4	+2.3	1.8	−2.2	3.2	+0.2
0.5	+2.0	1.9	−2.4	3.3	+0.9
0.6	+1.7	2.0	−2.6	3.4	+1.6
0.7	+1.3	2.1	−2.8	3.5	+2.2
0.8	+1.0	2.2	−2.9	3.6	+2.5
0.9	+0.7	2.3	−3.0	3.7	+2.7
1.0	+0.4	2.4	−3.0	3.8	+2.9
1.1	+0.1	2.5	−2.9	3.9	+3.0
1.2	−0.3	2.6	−2.7	4.0	+3.0
1.3	−0.6	2.7	−2.5		

I employed as the initial epoch for computing the times of minima the mean of the two best-determined epochs, viz., Campbell's minimum on September 1, 1899, and mine on January 13, 1901. The initial epoch is thus obtained:

$$\text{Minimum} = 5149^{\mathrm{d}}.01.$$

With these figures I will now correct for periodic motion the determinations of the velocity of *Polaris* so far published, in order to prepare the observed data for the investigation of the secular motion.

I. OBSERVERS: VOGEL AND SCHEINER.

(*Publ. des Astrophys. Obs. zu Potsdam*, Bd. VII, Theil I, p. 96.)

No.	Gr. M. T.	Julian	V	Minimum		A	B	R
				No.	Epoch			
	h	d	km		d	d	km	km
1	1888 Nov. 14 6.1	0956.25	−23.5	1	0944.52	1.73	−2.0	−25.5
2	Dec. 6 8.2	0978.34	−28.2	7	0978.33	0.01	+3.0	−25.2

It is seen that after allowance for the periodic motion, the two observations, which are the mean of the measures of Vogel and Scheiner, come into surprisingly good agreement.

Mean: R = − 25.33 km, for 1888 Nov. 25.3 ($0967^{d}.3$).

II. OBSERVER: CAMPBELL.

(*Publ. of the Ast. Soc. of the Pacific*, 11, 195.)

No.	Gr. M. T.	Julian	V	Minimum		A	B	R
				No.	Epoch			
	h	d	km		d	d	km	km
1	1896 Sept. 8 22.8	3811.95	−20.1	721	3811.69	0.26	+2.7	−17.4
2	15 22.8	3818.95	−19.1	722	3815.66	3.29	+0.8	−18.3
3	23 21.4	3826.89	−18.9	724	3823.60	3.29	+0.8	−18.1
4	Oct. 5 21.0	3838.88	−19.0	727	3835.50	3.38	+1.5	−17.5
5	Nov. 11 19.3	3875.80	−20.1	737	3875.18	0.62	+1.6	−18.5
6	12 (18.)	3876.75	−16.9	737	3875.18	1.57	−1.5	−18.4
7	Dec. 8 16.7	3902.70	−20.3	743	3898.99	3.71	+2.7	−17.6
8	1899 Aug. 9 0.8	4876.03	−13.0	989	4875.20	0.83	+0.9	−12.1
9	9 20.1	4876.84	−10.8	989	4875.20	1.64	−1.7	−12.5
10	14 22.8	4881.95	− 8.9	990	4879.17	2.78	−2.3	−11.2
11	16 0.1	4883.00	−13.9	990	4879.17	3.83	+2.9	−11.0
12	23 0.3	4890.01	−10.7	992	4887.10	2.91	−1.6	−12.3
13	24 0.8	4891.03	−15.0	992	4887.10	3.93	+3.0	−12.0
14	26 0.9	4893.04	− 9.0	992	4887.10	1.97	−2.5	−11.5
15	27 0.3	4894.01	−10.6	993	4891.07	2.94	−1.5	−12.1
16	27 16.2	4894.68	−14.0	993	4891.07	3.61	+2.5	−11.5
17	28 0.8	4895.03	−14.5	993	4891.07	3.96	+3.0	−11.5
18	28 16.3	4895.68	−13.7	993	4891.07	0.64	+1.5	−12.2
19	29 0.4	4896.02	−12.1	994	4895.04	0.98	+0.5	−11.6
20	29 18.8	4896.78	− 9.6	994	4895.04	1.74	−2.0	−11.6
21	30 0.0	4897.00	− 8.9	994	4895.04	1.96	−1.5	−11.4
22	30 16.2	4897.68	− 9.3	994	4895.04	2.64	−2.6	−11.9
23	Sept. 4 16.2	4902.68	−14.1	995	4899.01	3.67	+2.6	−11.5
24	6 18.1	4904.75	− 9.2	996	4902.98	1.77	−2.1	−11.3
25	11 16.2	4909.68	− 9.4	997	4906.94	2.74	−2.4	−11.8
26	11 22.5	4909.94	−10.7	997	4906.94	3.00	−1.2	−11.9
27	11 23.1	4909.96	−11.0	997	4906.94	3.02	−1.1	−12.1
28	12 23.6	4910.98	−14.6	998	4910.91	0.07	+2.9	−11.7

The extraordinarily high accuracy of Campbell's observations appears from the good agreement of the reduced velocities *R*. The probable error of the result of one plate comes out for the observations in 1896, ±0.31 km, for those in 1899, ±0.26 km.

Mean: R = —17.97 km, for 1896, Oct. 17.3 (3850^{d}.3),
R = —11.75 km, for 1899, Aug. 28.6 (4895.6).

III. OBSERVER: FROST.

(ASTROPHYSICAL JOURNAL, 10, 184, 1899.)

No.	Gr. M. T.	Julian	V	Minimum		A	B	R
				No.	Epoch			
	h	d	km		d	d	km	km
1	1899 Aug. 10 20.8	4877.87	−12.0	989	4875.20	2.67	−2.6	−14.6
2	Sept. 20 19.2	4918.80	−17.7	999	4914.88	3.92	+3.0	−14.7
3	27 16.0	4925.67	−10.6	1001	4922.82	2.85	−1.9	−12.5

Mean: R = − 13.93 km, for 1899, Sept. 9.4 (4907^{d}.4).

The difference of 2.18 km between the results of Campbell and Frost of nearly the same date is noticeable, and leads us to infer a systematic error in one of the two series of observations —probably in that of Frost. The difference is, nevertheless, so small that we may recognize in the agreement of the two results a sure proof of the correctness of the value of *R*.

This series of observations exhibits the peculiarity that the application of the corrections does not improve the agreement of the separate results, but on the contrary makes it decidedly worse. The five successive observations Nos. 12 to 16, for instance, should show clearly the periodic variation of *V;* but instead of this *V* was found to be very nearly constant while the periodicity now comes out strongly in the values of *R*. I believe this can be explained as follows: The velocity of *Polaris* relative to the Earth at the time of these observations was very nearly zero, so that the stellar spectrum could show only a slight diplacement from the comparison spectrum. In the method of coincidences employed by Bélopolsky such small displacements are very difficult to measure, and the observer is hence caused to derive almost the same displacement, zero, on the probably

IV. OBSERVER: BÉLOPOLSKY.

(*Astron. Nach.* 152, 199.)

No.	Gr. M. T.	Julian	V	Minimum		A	B	R
				No.	Epoch			
		d	km		d	d	km	km
1	1899 Nov. 23.34	4982.34	− 8.5	1016	4982.34	0.00	+3.0	− 5.5
2	29.25	4988.25	− 6.9	1017	4986.31	1.94	−2.5	− 9.4
3	30.34	4989.34	− 7.1	1017	4986.31	3.03	−1.0	− 8.1
4	Dec. 3.30	4992.30	− 8.2	1018	4990.28	2.02	−2.6	−10.8
5	19.37	5008.37	− 8.2	1022	5006.15	2.22	−2.9	−11.1
6	1900 Jan. 3.24	5023.24	−10.6	1026	5022.02	1.22	−0.4	−11.0
7	12.24	5032.24	− 7.9	1028	5029.96	2.28	−3.0	−10.9
8	14.21	5034.21	−10.7	1029	5033.93	0.28	+2.6	− 8.1
9	15.28	5035.28	− 8.7	1029	5033.93	1.35	−0.8	− 9.6
10	16.22	5036.22	− 5.5	1029	5033.93	2.29	−3.0	− 8.5
11	18.22	5038.22	− 8.1	1030	5037.90	0.32	+2.5	− 5.6
12	March 22.43	5101.43	−10.7	1046	5101.39	0.04	+3.0	− 7.7
13	23.41	5102.41	− 9.9	1046	5101.39	1.02	+0.3	− 9.6
14	24.41	5103.41	−11.7	1046	5101.39	2.02	−2.6	−14.3
15	25.40	5104.40	− 9.6	1046	5101.39	3.01	−1.1	−10.7
16	26.37	5105.37	−10.4	1047	5105.36	0.01	+3.0	− 7.4
17	30.43	5109.43	− 9.7	1048	5109.33	0.10	+2.9	− 6.8

insufficiently sharp plates taken on successive days. The value of *V* arises for the most part from the reduction to the Sun (−12 km). Bélopolsky accordingly draws the correct conclusion that on account of their great uncertainty his results can hardly contribute to our knowledge of the changes in the velocity of the star. A probable error ±1.5 km is found for the value of *R* and *V* given in the above table, which for the most part give the mean of two plates taken on the same day.

Mean: R = −9.12 km, for 1900, Jan. 26.2 ($5046^{d}.2$).

This mean value differs from Campbell's observations as well as from those of my own, next to be discussed, in the sense that the amount of the negative velocity was found too small by about 3 km by Bélopolsky. Since his observations of *ζ Geminorum*[1] deviate in the same direction from Campbell's, we may conclude that the spectrograms used by Bélopolsky are affected by very appreciable systematic errors.

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[1] See CAMPBELL, "The Motion of *ζ Geminorum* in the Line of Sight," ASTROPHYSICAL JOURNAL, 13, 90, 1901.

V. OBSERVER: HARTMANN.

(See Table I.)

No.	Gr. M. T	Julian	V	Minimum No.	Minimum Epoch	A	B	R
		d	km		d	d	km	km
1	1900 March 7.42	5086.42	−15.1	1042	5085.52	0.90	+0.7	−14.4
2	9.44	5088.44	−14.2	1042	5085.52	2.92	−1.6	−15.8
3	10.42	5089.42	−13.1	1042	5085.52	3.90	+3.0	−10.1
4	11.31	5090.31	−11.7	1043	5089.49	0.82	+0.9	−10.8
5	14.48	5093.48	−17.1	1044	5093.45	0.03	+3.0	−14.1
6	21.49	5100.49	−12.7	1045	5097.42	3.07	−0.8	−13.5
7	April 2.38	5112.38	−13.8	1048	5109.33	3.05	−0.9	−14.7
8	3.37	5113.37	−17.7	1049	5113.30	0.07	+2.9	−14.8
9	4.36	5114.36	−15.3	1049	5113.30	1.06	+0.2	−15.1
10	5.42	5115.42	− 9.8	1049	5113.30	2.12	−2.8	−12.6
11	23.40	5133.40	−16.4	1054	5133.14	0.26	+2.7	−13.7
12	24.45	5134.45	−13.6	1054	5133.14	1.31	−0.6	−14.2
13	25.36	5135.36	− 4.7	1054	5133.14	2.22	−2.9	− 7.6
14	Nov. 7.33	5331.33	−14.2	1103	5327.58	3.75	+2.8	−11.4
15	8.25	5332.25	−12.8	1104	5331.55	0.70	+1.3	−11.5
16	8.38	5332.38	−14.0	1104	5331.55	0.83	+0.9	−13.1
17	8.69	5332.69	−12.6	1104	5331.55	1.14	−0.1	−12.7
18	9.22	5333.22	− 9.7	1104	5331.55	1.67	−1.8	−11.5
19	Dec. 3.40	5357.40	− 9.6	1110	5355.36	2.04	−2.7	−12.3
20	1901 Jan. 8.23	5393.23	−10.7	1119	5391.08	2.15	−2.8	−13.5
21	8.36	5393.36	−11.5	1119	5391.08	2.28	−3.0	−14.5
22	9.19	5394.19	−12.4	1119	5391.08	3.11	−0.5	−12.9
23	9.37	5394.37	−13.9	1119	5391.08	3.29	+0.8	−13.1
24	10.18	5395.18	−17.3	1120	5395.04	0.14	+2.9	−14.4
25	11.17	5396.17	−13.5	1120	5395.04	1.13	0.0	−13.5
26	11.39	5396.39	−12.9	1120	5395.04	1.35	−0.8	−13.7
27	14.18	5399.18	−15.4	1121	5399.01	0.17	+2.8	−12.6
28	14.37	5399.37	−15.9	1121	5399.01	0.36	+2.4	−13.5
29	15.18	5400.18	−12.6	1121	5399.01	1.17	−0.2	−12.8
30	16.18	5401.18	− 9.5	1121	5399.01	2.17	−2.9	−12.4
31	16.40	5401.40	−11.2	1121	5399.01	2.39	−3.0	−14.2
32	17.18	5402.18	−12.0	1121	5399.01	3.17	0.0	−12.0
33	17.44	5402.44	−15.3	1121	5399.01	3.43	+1.8	−13.5
34	18.35	5403.35	−15.1	1122	5402.98	0.37	+2.4	−12.7

These observations should be separated into two groups. The plates obtained in March and April 1900, when the spectrograph was exposed to all the changes of temperature, do not show a satisfactory agreement, as has been already mentioned above. At these dates the probable error of a single plate is ± 1.6 km. The largest deviation is shown by the plate of April 25, 1900. In the observation book it is recorded: "At a sudden clearing up the observation was very hastily begun. In consequence of this the star was not well set at the middle of the slit; the star spectrum lies far toward the side on the comparison spectrum, and cannot be measured with certainty. There would be good reason for excluding this plate, but the others would nevertheless give a probable error of ± 1.2 km, which is decidedly large in view of the great accuracy of the measures on each individual plate. The exceedingly good effect of the attachment of the thermostat on the agreement of the observations can be seen by a glance at the values of *R*—the probable error of a plate since November 1900, is but ± 0.49 km. This shows clearly enough how imporant it is that the spectrograph be kept at constant temperature during an exposure.

It may be seen from these figures that the plates now obtained with spectrograph III possess a very high degree of accuracy, although they are still a little inferior to those secured by Campbell with the Mills spectrograph, which have not yet been equaled by plates elsewhere. The reason why my plates have not hitherto further increased in accuracy appears to lie in a small systematic error which usually clearly appears on evenings when more than one plate is made. The following summary gives the comparison of the values of *R* obtained on such evenings.

	First plate	Second plate	II — I
	km	km	km
1900 Nov. 8......	−11.5	−13.1	−1.6
1901 Jan. 8......	−13.5	−14.5	−1.0
9......	−12.9	−13.1	−0.2
11......	−13.5	−13.7	−0.2
14......	−12.6	−13.5	−0.9
16......	−12.4	−14.2	−1.8
17......	−12.0	−13.5	−1.5

The second plate on each of the seven evenings accordingly shows a stronger negative motion than the first, and there can be no doubt that there has been a disturbing source of error dependent either upon the time or the hour-angle of the star. I hope to succeed in discovering this error and in suppressing it, which would obviously greatly increase the accuracy of the results. As long as this unknown source of error continues, all the measured velocities may be uncertain by a small systematic amount.

As my observations are separated by considerable intervals of time, I combine them in the three following mean values:

R = — 13.18 km for 1900 March 29.3 (5108^{d}.3)
R = — 12.07 1900 Nov. 12.5 (5336.5)
R = — 13.29 1901 Jan. 13.1 (5398.1)

The first of these is to be regarded as uncertain, as stated above.

In attempting to get a preliminary survey of the progress of the secular motion from the data collected here, we should note the following points. The Potsdam observations of 1888 may indeed, as experience has shown, be affected by systematic errors of several kilometers, but the great value that they possess on account of their early date is not diminished. But Frost's result, which is based on only three observations, does not come into consideration in comparison with the simultaneous observations of Campbell. I also omit the results of Bélopolsky's plates, on account of the possibility of large systematic errors, as well as those of my own plates made without the thermostat. There remain the following values of the secular motion:

1888	November 25,	*R* = — 25.35 km	(Vogel and Scheiner)
1896	October 17,	— 17.97	(Campbell)
1899	August 29,	— 11.75	(Campbell)
1900	November 12,	— 12.07	(Hartmann)
1901	January 13,	— 13.29	(Hartmann)

It appears from these figures that the reversal of the secular motion has occurred since 1899: the negative velocity, which grew smaller since 1888, is now on the increase. The star must be followed spectroscopically for years for the accurate determination of this motion.

But *Polaris* may be also an interesting object for direct micrometer measures. If from the values found for the secular motion we make the very rough estimate that the visible star in common with its invisible companion describes an orbit about a third body in about fifteen years with a velocity of some 6 km, then a simple computation shows that the diameter of this orbit must be at least three times that of the Earth's orbit. Hence it follows that in the course of that long period, the star must undergo changes of position which at least reach six times the value of its parallax. If we take Peters' value of 0″.07 for the parallax we get an amplitude of 0″.4 for the periodic variations in the position of the star, an amount which is sufficient to make itself felt even in absolute determinations of position.

MINOR CONTRIBUTIONS AND NOTES

THE PUBLICATIONS OF THE ALLEGHENY OBSERVATORY.

THE Allegheny Observatory was founded in 1859 by the Allegheny Astronomical Society, a body composed of a number of private citizens of Allegheny and Pittsburg. For several years after its completion the Observatory, and the 13-inch telescope with which it was equipped, was used by the various members of the society and their friends, in observing the physical features and appearances of the Moon, planets, satellites, double stars, etc. But no regular or systematic scientific work appears to have been undertaken. In June 1867 the Observatory property was transferred under deed of trust to the Western University of Pennsylvania, and in August of the same year the board of trustees of the university elected Professor Samuel Pierpont Langley as the first regular director of the Observatory.[1]

The long and brilliant line of astronomical and astrophysical investigations and discoveries that have been made at the Allegheny Observatory under the directorship of Professor Langley and his no less able and distinguished associate and successor, the late lamented Professor James E. Keeler, have entitled this institution to a position among the leading observatories of the world. The Observatory, unfortunately both for itself and others, has not heretofore had the means to publish under its own auspices, the results of its work, and the records of its investigations and discoveries have, as a consequence, never been brought together in a collected form, but are scattered through many scientific journals and magazines, the proceedings and transactions of different scientific societies of this country and of Europe, and various official publications of the United States government, and the Smithsonian Institution. To obtain a complete and continuous record of the past work of our Observatory I have recently taken great pains to compile what I believe to be a full and accurate list of all the scientific papers that have been published from the Observatory from 1869 to the end of 1900, by the various members of its staff. The history of the scientific activity of the Observatory during these thirty-one years of work is contemporaneous and closely identified with the history of the development of the "new astronomy," and this list of papers may therefore be of interest and value to the student of astrophysics. For this reason, and for the benefit of our exchanges, I have decided to publish it, together with a brief statement concerning the plans that have been formed in regard to future publications.

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[1] For further details concerning the early history of the Allegheny Observatory see address by Mr. Brashear, "The Allegheny Observatory," *Pop. Ast.*, **8**, 541, Dec. 1900.

The papers in the following list are arranged as nearly as possible in the order of the date of publication. To save unnecessary repetitions of names, titles, etc., the following abbreviations have been used:[1]

S. P. L. Professor S. P. Langley. (Director of the Observatory, 1867–1891.)

J. E. K. Professor James E. Keeler. (Assistant Astronomer, 1881–1883; 1884–1886; Director of the Observatory, 1891–1898.)

F. W. V. F. W. Very. (Assistant to the Director, 1878–1890; Adjunct Professor of Astronomy, 1890–1895.)

J. A. B. John A. Brashear. (Acting Director of the Observatory, 1898–1899; Chairman Observatory Committee.)

F. L. O. W. Professor F. L. O. Wadsworth. (Director of the Observatory, 1900 —.)

The abbreviations for the titles of journals, proceedings of societies, etc., are the same as have been adopted by the ASTROPHYSICAL JOURNAL (see Vol. II, pp. 396–400, Dec. 1895), viz:

A. and A.	*Astronomy and Astrophysics.*
Am. Jour. Sci.	*American Journal of Science and Arts.*
Am. Met. Jour.	*American Meteorological Journal.*
Wied. Ann.	*Annalen der Physik und Chemie.*
Ann. Chim. et Phys.	*Annales de Chimie et de Physique.*
Ast. Jour.	*Astronomical Journal.*
A. N.	*Astronomische Nachrichten.*
Ap. J.	*Astrophysical Journal.*
Bull. Astr.	*Bulletin Astronomique.*
Bull. Phil. Soc.	*Bulletin of the Philosophical Society of Washington.*

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[1] The list comprises only papers of a scientific or technical character. A number of popular articles, written by Professor Langley for the Pittsburg, New York, and London daily papers, are not included, and several reviews of the work of other investigations, written by Professor Keeler, have likewise been omitted for the reason that they had no reference or relation to the work of the Observatory.

C. R.	*Comptes Rendus de l'Academie des Sciences.*
Jour. B. A. A.	*Journal of the British Astronomical Association.*
Jour. Franklin Inst.	*Journal of the Franklin Institute.*
Mem. Nat. Acad.	*Memoirs of the National Academy of Sciences* (Washington).
Mem. R. A. S.	*Memoirs of the Royal Astronomical Society.*
Mem. Spettr. Ital.	*Memorie della Società degli Spettroscopisti Italiani.*
M. N.	*Monthly Notices of the Royal Astronomical Society.*
Nat.	*Nature.*
Obs'y.	*Observatory.*
Phil. Mag.	*Philosophical Magazine.*
Photo. Times.	*Photographic Times.*
Pop. Astron.	*Popular Astronomy.*
Proc. American Acad.	*Proceedings of the American Academy of Arts and Sciences.*
Proc. R. Inst.	*Proceedings of the Royal Institution of Great Britain.*
Proc. R. Soc.	*Proceedings of the Royal Society of London.*
Pub. A. S. P.	*Publications of the Astronomical Society of the Pacific.*
Report A. A. A. S.	*Report of the American Association for the Advancement of Science.*
Report B. A. A. S.	*Report of the British Association for the Advancement of Science.*
Sid. Mess.	*Sidereal Messenger.*
Trans. Ast. Phys. Soc. Toronto.	*Transactions of the Astronomical and Physical Society of Toronto.*

The volume is indicated by the first figures (in heavy type) following the abbreviation for the title of the journal, the page numbers (inclusive) by the following figures.

No.

*1. Proposal for a Railway Time Service, by S. P. L.; 8 pp., 8vo, Dec. 1869.

2. The American Eclipse Expedition to Xeres, Spain, by S. P. L.; *Nat.*, **3**, 228, 229, Jan. 19, 1871.

3. The Total Solar Eclipse of Dec. 22, 1870. Letter from Jerez de la Frontera, by S. P. L.; *Jour. Franklin Inst.*, **61**, 88, Feb. 1871.

4. A New Form of Solar Eyepiece, by S. P. L.; *Jour. Franklin Inst.*, **61**, 115–117, Feb. 1871.

5. On the Allegheny System of Electric Time Signals, by S. P. L.; *Am. Jour. Sci.* (Ser. 3), **4**, 377–387, Nov. 1872.

*6. Allegheny Observatory, *Report of the Director*, by S. P. L.; 8 pp., 8vo, June 1873

No.

7. The Solar Photosphere, by S. P. L.; *Proc. A. A. A. S.*, **22**, 161–174, 1873.

8. Uniform Railway Time, by S. P. L.; *American Exchange and Review*, **24**, 271–276, Jan. 1874.

*9. On the Minute Structure of the Solar Photosphere, by S. P. L.; *Am. Jour. Sci.* (Ser. 3), **7**, 87–102, Feb. 1874.

*10. The External Aspects of the Sun, by S. P. L.; *Jour. Franklin Inst.*, **68**, 123–134; 207–212, Aug. and Sept. 1874.

*11. On the Comparison of Certain Theories of Solar Structure with Observation, by S. P. L.; *Am. Jour. Sci.* (Ser. 3), **9**, 192–198, Mar. 1875. *Mem. Spettr. Ital.*, **4**, 1–8, 1875.

12. Sur la Temperature relative des diverses Regions du Soleil, by S. P. L.; *C. R.*, **80**, 746–749, 819–822, Mar. 1875.

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*14. The Solar Atmosphere, by S. P. L.; *Am. Jour. Sci.* (Ser. 3), **10**, 489–497, Sup. No. 1875.

*15. Measurement of the Direct Effect of Sun-spots on Terrestial Climates, by S. P. L., *M. N.*, **37**, 5–11, Nov. 1876.

*16. Nouvelle Methode Spectroscopique, by S. P. L.; *C. R.*, **84**, 1145–1147, May 1877.

*17. On the Possibility of Transit Observations without Personal Error, by S. P. L.; *Am. Jour. Sci.* (Ser. 3), **14**, 55–60, July 1877.

*18. A proposed New Method of Solar Spectrum Analysis, by S. P. L.; *Am. Jour. Sci.* (Ser. 3), **14**, 140–146, Aug. 1877.

*19. On the Janssen Solar Photograph and Optical Studies, by S. P. L.; *Am. Jour. Sci.* (Ser. 3), **15**, 297–301, Apr. 1878.

*20. Transit of Mercury May 6, 1878, by S. P. L.; *Am. Jour. Sci.* (Ser. 3), **15**, 457–459, June 1878.

21. The Total Solar Eclipse of July 29, 1878, by S. P. L.; *U. S. Naval Obs'y Reports 1878*, 203–210.

22. On Certain Remarkable Groups in the Lower Spectrum, by S. P. L.; *Proc. American Acad.* (New Ser.), **6**, 92–105, 1878.

23. On the Temperature of the Sun, by S. P. L.; *Proc. American Acad.* (New Ser.), **6**, 106–113, Oct. 1878.

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*35. Observations du Spectre Solaire, by S. P. L.; *C. R.*, **95**, 482–487, Sept 1882.

*36. Sunlight and Skylight at High Altitudes, by S. P. L.; *Am. Jour. Sci.* (Ser. 3), **24**, 393–398, Nov. 1882.

*37. The Transit of Venus, by S. P. L.; *A. N.*, No. 2481, **104**, 142, Jan. 1883.

38. Observations of the Transit of Venus Dec. 6, 1882, by S. P. L.; *M. N.*, **43**, 71–73, Jan. 1883.

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47. Sur l'Absorption Selective de l'Energie Solaire, by S. P. L.; *Ann. Chim. et Phys.* (Ser. 5), **29**, 497–542, Aug. 1883.

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It is no longer possible to furnish or to obtain complete sets of these papers. Indeed, as far is known here, there are only one or two complete collections in existence. We still have copies of those papers marked with a star [*] in the preceding list, *i. e.*, of Nos. 1, 6, 9, 10, 11, 14, 15, 16, 17, 18, 19, 20, 26, 30, 35, 36, 37, 41, 42, 45, 46, 49, 51, 53, 54, 56, 58, 59, 60, 61, 62, 66, 67, 68, 69, 70, 71, 72, 75, 76, 77, 78, 80, 82, 87, 90, 91, 92, 98, 101, 102, 103, 112, 115, 116, 117, 119, 129, 133, 137, 138, and 141.

We shall be very glad to send copies of any of the above to our past contributors to enable them to complete their collections as far as is now possible. Applications for the separate numbers will, in general, be filled in the order in which they are received, until the supply of each is exhausted, but as the number of copies is in many cases limited, we must, when it is necessary, give the preference to those to whom the Observatory is most indebted for past contributions.

PUBLICATIONS OF THE NEW OBSERVATORY.

The future publications of the Allegheny Observatory will be divided into two series: (1) *The Annals of the Allegheny Observatory*, in the form of quarto volumes of uniform size and binding, containing detailed descriptions of instruments, methods of work and results of special researches and continued series of observations; and (2) *Miscellaneous Scientific Papers of the Allegheny Observatory*, consisting of reports, special announcements, bulletins, and reprints of papers communicated to the various scientific journals and societies.[1] The successive papers of the second series will be numbered consecutively in the order of the date of publication, and will be issued as far as possible in uniform octavo size, 6 inches by 9 inches, so that they may subsequently be bound together if desired in volume form. It will probably be impossible or inexpedient to reprint all of the shorter and less important communications to journals and societies in sufficient numbers for complete exchange and distribution, but in such cases, for the sake of uniformity and continuity of record, numbered title pages only giving the place and date of publication of the article will be issued.

In conclusion, I take this opportunity to extend on the part of the Observatory, our most sincere thanks to all of those who have so kindly and generously contributed to our library in the past, and to cordially invite all of those who have not already done so to arrange for an exchange of publications in the future.

A detailed acknowledgment of the more recent and valuable gifts to the library, and as far as possible a complete list of our contributors and exchanges, will be published in the first volume of our *Annals*, which it is intended to devote to a full description of our new Observatory buildings, instruments, library, and general equipment; together with a short history of the administration and scientific work of the old Observatory. Part of the manuscript of this volume is already prepared, and it will be issued as soon as the new Observatory and its principal instruments are completed.

F. L. O. WADSWORTH.

ALLEGHENY OBSERVATORY,
May 1901.

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[1] The present paper forms No. 3 of this series.

SPECTRUM OF *NOVA PERSEI* NO. 2.[1]

The star *Nova Persei* No. 2, has now become so faint that its spectrum can no longer be photographed satisfactorily with a large dispersion. Moreover, it is, at sunset, so low in the northwest that it cannot be observed to advantage in the evening. A series of photographs of its spectrum, ever since its appearance, has been made with the 11-inch Draper telescope. At first, two prisms were used, giving a spectrum in which the distance from $H\epsilon$ to $H\beta$ is 3.76 cm. After March 19 it was found that, owing to the diminishing light, better results could be obtained with one prism, giving a spectrum in which the distance from $H\epsilon$ to $H\beta$ is 1.80 cm. Meanwhile, a second series of spectra has been obtained with the 8-inch Draper telescope with much smaller dispersions, the distances between the lines $H\epsilon$ and $H\beta$ being 0.57 cm., and 0.14 cm., respectively. Care was taken, when the *Nova* was bright, to allow the spectrum to trail, or to give it a rapid motion over the plate, so that it should not be over-exposed with these small dispersions. These photographs will, therefore, be comparable with those taken when the star becomes very faint. It is expected that the spectrum can thus be studied even when the star is of the tenth magnitude or fainter, although its light will have diminished more than ten thousand times. The series of spectra taken with the 11-inch Draper telescope is now completed, unless the star should again become bright. A careful study of these photographs has been made by Miss Annie J. Cannon and will be published in the *Annals*. A brief summary of the results is given below. The principal bright lines are accompanied by dark lines on the edge of shorter wave-length. All of the wave-lengths have been referred to the centers of these bright lines, since after March 23 the dark hydrogen lines disappeared.

A description of the spectrum of *Nova Persei* No. 2, as photographed here on February 22, 23, and 24, 1901, is given in *Circular* No. 56. Plates taken since February 24 show numerous changes. Narrow dark lines, probably due to reversal, appeared upon the bright bands, and the latter increased in intensity with respect to the continuous spectrum. The dark bands became narrower, and, in some cases, separated into two or more parts. A peculiar dark band between $H\eta$ and $H\zeta$, and extending from λ 3845 to λ 3856, which was as intense as $H\zeta$ on Februrary 24, faded very rapidly and was not seen after February

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[1] *Harvard College Observatory Circular* No. 59.

28. A dark band near $H\delta$, and having wave-length 4056 to 4069 on February 24, showed peculiar changes in intensity, width, and wave-length. The dark bands of hydrogen became double, and then grew fainter, and in place of the hazy bands two narrow, dark lines appeared. The dark band K also became double and decreased in intensity. On March 17, $H\zeta$, $H\epsilon$, $H\delta$, and $H\gamma$, each consisted of a narrow, sharply defined, dark line, and on the most careful inspection, an extremely faint component, well separated, was seen towards the violet. $H\beta$ was clearly double, the faint component being well marked. The wide dark band, K, had entirely disappeared, and a narrow dark line remained, which was only slightly more intense than the reversed K.

On March 19 there appears to have been a peculiar change in the spectrum. No dark lines were present, except the fine lines due to reversal superposed on the bright bands, and the continuous spectrum was almost invisible. The line K was absent. The plate on this date was taken with two prisms and exposed 120^{m}. A peculiar broadening, or displacement towards the violet, of the bright band $H\zeta$ had taken place since March 17. On March 19 this band extended more than half way to $H\eta$. On March 23 the continuous spectrum was present and narrow dark lines were seen on the edges of shorter wave-length of the bright light lines $H\epsilon$, $H\delta$, and $H\gamma$. Three other dark bands were present, and several bright bands besides those of hydrogen. The position of $H\zeta$ was normal. On March 27 a strong continuous spectrum was seen, but the dark components of the hydrogen bands were absent, and have not been seen since. A well marked, narrow, dark line was present at wave-length 3865, and a fainter dark line at λ 3860. There was a hazy, dark band extending from λ 3806 to λ 3827, and a bright band from λ 4453 to λ 4489, both of which appeared to coincide with helium lines. The position of $H\zeta$ was normal. On March 30 the spectrum was like that of March 27, except that line λ 3865 was more intense, and λ 3860 was not seen. The continuous spectrum, which was very intense, was photographed far into the violet, but no lines were distinctly seen beyond a hazy, dark band which extended from wave-length 3775 to 3794. The bright band λ 4908 to λ 4942 was very faint, and the band λ 4990 to λ 5040 was brighter than the magnesium band, *b*. On April 1 the spectrum was nearly the same as on March 30. Owing to a long period of cloudy weather, no good plates were obtained from April 1 to April 12, when a peculiar spectrum was photographed. $H\zeta$ appeared to be missing, and near its place there was a bright band as intense as $H\beta$, whose center was λ 3875. This band, $H\epsilon$ and $H\delta$, were very sharply defined towards the red, and hazy towards the violet. It is of interest to note that a dark band of well-marked intensity occurs in the spectrum of γ *Velorum* at wave-length 3875. A peculiar bright line appeared in the *Nova* on April 12 near $H\gamma$, on the side of greater wave-length. The wave-length of this line is 4384, and it was quite sharply defined towards the red, while the space between it and the bright band $H\gamma$ appeared somewhat like a faint bright band. On April 13 the position and intensity of $H\zeta$ were normal, and, although the plate was poor, the spectrum was not of the peculiar type of April 12. This peculiar spectrum was, however, photographed again on April 26, when the peculiarities were even more marked than on April 12. Band λ 3875 was the most intense bright band on April 26. Band λ 4990 to λ 5040 had also increased in intensity, while $H\delta$ and $H\beta$ had diminished. $H\gamma$ was more intense than $H\beta$. The continuous spectrum was absent. Bands λ 4908 to λ 4942, and the magnesium band, *b*, were not seen. On April 27 the spectrum was again normal. Band λ 3875 was absent, and the continuous spectrum was of well-marked intensity. In general, the spectrum appeared to be like that of March 30. On April 28 the spectrum was again peculiar, and like that of April 26. The bright bands, which were very sharply defined on the edge of greater wave-length on April 12, were on April 26, sharply defined on the edge of shorter wave-length. When the plate taken on April 12 is superposed upon that of April 26, this difference in the definition of the bands is very striking.

On May 1 and 3 the spectrum was peculiar and like that of April 28. Photographs were attempted on May 6 and 7, but the *Nova* was evidently too low and the glare of sunset prevented success. Nothing is seen on the plates. It thus appears that two types of spectra have been visible from March 19 to May 3. Photographs of the peculiar spectrum were obtained on March 19, April 12, 26, 28, May 1 and 3; of the normal spectrum on March 23, 27, 30, April 1, 13, and 27. It is interesting to note the connection between the changes in the spectrum and in the light of the *Nova*, for on all the dates on which the peculiar spectrum was photographed, a minimum occurred, according to the Harvard visual and photometric observations, except on April 12. The magnitude of the star was the same on April 12 and 13, while the spectrum was different. On April 26 and 28, however, there occurred marked minima, and the peculiar spectrum was photographed on both dates, while on the intermediate evening, April 27, when the *Nova* was about a magnitude and a half brighter than on either the preceding or following night, the spectrum was normal.

The following table shows the connection between the spectrum and the magnitude of the *Nova*. The first column gives all the dates on which the *Nova* was successfully photographed at Harvard with the 11-inch telescope from March 17 to May 3, 1901. The second column gives the character of the spectrum. The third column gives the magnitude from visual observations reduced to the photometric scale.

RELATION OF SPECTRUM TO MAGNITUDE.

Date	Spectrum	Mag.	Date	Spectrum	Mag.	Date	Spectrum	Mag.
March 17	Normal	3.8	April 1	Normal	4.1	April 27	Normal	4.2
March 19	Peculiar	5.0	April 12	Peculiar	4.6	April 28	Peculiar	5.4
March 23	Normal	3.6	April 13	Normal	4.6	May 1	Peculiar	5.3
March 27	Normal	4.1	April 26	Peculiar	5.8	May 3	Peculiar	5.5
March 30	Normal	4.2						

THE SPECTRUM OF η *Carinae.*

On April 16, 1898, Miss Cannon, while examining plates taken in Arequipa for the classification of stellar spectra, recorded the statement regarding *Nova Aurigae*, "Spectrum made up almost entirely of bright bands that coincide in position with those of η *Carinae*." This is followed by a detailed description of the spectrum of η *Carinae*, and a comparison with the spectrum of *Nova Aurigae*, including the bright and dark hydrogen lines, which is incorporated in the "Remarks" in the *Annals* Vol. XXVIII, p. 175, now in the hands of the printer. Photographs pointing out this resemblance were contained in the exhibit of the Harvard Observatory at Paris in 1900, and are now in the Buffalo Exhibition.

EDWARD C. PICKERING.

June 6, 1901.

NOVA PERSEI, NO. 2.

AN examination of the Draper photographs of the spectra of *Nova Persei*, No. 2, by Mrs. Fleming, shows that, like other *novae*, it has been gradually changing into a gaseous nebula. The resemblance to the nebula *N. G. C. 3918* is now so close that in a photograph taken on June 19, 1901, no marked difference was noted, except that the nebular line λ 5007 is about eight times as bright as $H\beta$ in the nebula, and only equal to it in the *Nova*. The lines λ 3869, 3970 ($H\epsilon$), 4102 ($H\delta$), 4341 ($H\gamma$), 4688, 4862 ($H\beta$), 4959, and 5007, are common to both and, except the last, have nearly the same relative intensities. Four bright lines between $H\gamma$ and $H\beta$ appear faintly in the *Nova* and are not present in the nebula, while one, λ 4364, is seen in the nebula but not in the *Nova*, perhaps owing to the proximity of $H\gamma$.

EDWARD C. PICKERING.

June 25, 1901.

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The scope of the ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory. The subjects to which special attention will be given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric, and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

In the department of *Minor Contributions and Notes* subjects may be discussed which belong to other closely related fields of investigation.

Articles written in any language will be accepted for publication, but unless a wish to the contrary is expressed by the author, they will be translated into English. Tables of wave-lengths will be printed with the short wave-lengths at the top, and maps of spectra with the red end on the right, unless the author requests that the reverse procedure be followed. If a request is sent *with the manuscript* one hundred reprint copies of each paper, bound in covers, will be furnished free of charge to the author. Additional copies may be obtained at cost price. No reprints can be sent unless a request for them is received before the JOURNAL goes to press.

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THE ABSORPTION SPECTRUM OF CHLORINE.

By ELIZABETH R. LAIRD.

HISTORICAL INTRODUCTION.

In 1833 Brewster[1] discovered that the spectrum of white light which has passed through a layer of nitrogen peroxide is crossed by a number of black lines. It was natural that physicists should at once begin to look for similar phenomena in the case of other gases, and the colored ones received particular attention. W. H. Miller and Daniell[2] found such absorption lines with iodine, bromine and euchlorine (a mixture of chlorine and its oxides). The lines produced by iodine and bromine appeared to be equidistant and of equal intensity. Using pure chlorine they failed to find anything but a general absorption in the violet. W. A. Miller[3] investigated a number of gases in this connection, and made rough drawings of the absorption spectra of iodine, bromine, nitrogen peroxide, chlorine dioxide, and "perchloride of manganese;" but he also failed to obtain a line absorption due to chlorine. His apparatus, however, consisted only of a

[1] *Phil. Mag.* [3], **2**, 360, 1833; **8**, 384, 1836.

[2] *Pogg. Ann.*, **28**, 386, 1833.

[3] *Phil. Mag.* [3], **27**, 81, 1845.

telescope and a single flint-glass prism placed twenty feet from a slit admitting diffused daylight; and it is not certain that he used a column of more than nine inches of chlorine. Later, in 1859, M. E. Robiquet[1] stated that there was not the least appearance of lines in the spectrum of chlorine even when the light had passed through 4.5 meters of the gas, but that the spectrum consisted of a general illumination in the green and yellow. His source of light was an incandescent platinum wire, and he used a single-prism spectroscope. Many other attempts were made to discover a chlorine line absorption spectrum, as the known similarities between this gas and bromine and iodine led to the belief that such a spectrum existed; but all these attempts failed on account of the lack of suitable apparatus. Finally, in 1869, Morren,[2] using a spectroscope of fine flint-glass prisms and a length of two meters of chlorine, succeeded in obtaining the desired spectrum. He gives a general description of its appearance. According to his observations the lines begin above the *b* solar lines and extend below F to about λ4820. Beyond λ4750 the sunlight is totally absorbed. The lines differ in intensity, width and grouping, and are placed irregularly. He mentions having made a drawing, but it was apparently not published. Later, Gernez[3] unaware of the previous work of Morren, rediscovered the lines. He tried first a length of 1.5 meters of chlorine at atmospheric pressure, but he obtained the lines more distinctly by using a tube of chlorine three times as long. His spectroscope had two prisms, and a Drummond lamp was the source of light. He states that this gives a spectrum extending into the "violet," that the lines begin a little below the D lines and extend to the "violet," which is totally absorbed. He remarks also that the lines are unlike those of bromine and iodine in having variable intensity and irregular grouping.

Liveing and Dewar[4] have investigated the general absorption of chlorine in the ultra-violet. As a source of light they used the spark of an induction coil between iron electrodes. The tubes used had quartz ends and the dispersing prism was of quartz. They found that a small quantity of chlorine gave one absorption band stretching from λ3560–λ3020. As the quantity of chlorine was increased the band widened, and the following different measurements of its width are given — λ3968–λ2755; λ4415–λ2665; λ4650–λ2630; with the greatest amount of chlorine used they found that the absorption stopped at λ2550.

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[1] *C. R.*, **49**, 606, 1859.

[2] *Pogg. Ann.*, **137**, 165, 1869; *C. R.* **68**, 376, 1869.

[3] *C. R.*, **74**, 660, 1872.

[4] *Chem. News*, **47**, 121, 1883.

The absorptive power of chlorine for the long heat rays was investigated by Tyndall.[1] He found that, excepting air, oxygen, nitrogen and hydrogen, it absorbed less than any other gas on which he experimented. K. Ångström and W. Palmaer[2] found that the infra-red spectrum consisted of a single band, which with an Argand lamp as source of radiation, and a column of 11.8 cm of chlorine, extended from λ32300 to λ60700 (Å. U.), the maximum absorption being at λ42800.

Liquid chlorine is said by Gänge[3] to absorb the extreme red down to about λ6970 or λ6860; from there on the light is transmitted to about λ5120, from which point absorption begins again, and is complete at λ5030.

The emission spectrum of chlorine has been investigated at different times. Plücker[4] was the first to obtain it, but in his first experiments the spectrum did not last long enough for purposes of drawing; later, together with Hittorf,[5] he studied its spectrum as obtained from Geissler tubes and made a careful drawing of it. Van der Willigen[6] and Salet[7] studied the spectrum of the gas at atmospheric pressure. The former used the spark from an induction coil, the latter used a Holtz machine;

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[1] TYNDALL, *Contributions to Molecular Physics in the Domain of Radiant Heat*, p. 80.

[2] *Öfversigt af K. Vet. Akad. Förhandl.*, No. 6, 389, 1893.

[3] GÄNGE, *Lehrbuch der angewandten Optik in der Chemie*, p. 217.

[4] *Pogg. Ann.*, **106**, 83, 1858.

[5] *Phil. Trans.*, **155**, 24, 1865.

[6] *Pogg. Ann.*, **106**, 624, 1859.

[7] *Ann. de Chim. et de Phys.* [4], **28**, 24, 1873.

both give drawings of the spectrum obtained. Ångström[1] and Hasselberg[2] measured a few lines. The latter remarked them in using vacuum tubes the glass walls of which contained chlorine. Lecoq de Boisbaudran[3] and Eugen Demarcay[4] identified as belonging to chlorine some lines obtained from the spark discharge between a platinum wire and hydrochloric acid; both give measurements on these lines. Ciamician[5] studied the relation of the spectrum of chlorine to the spectra of iodine and bromine; also the variation in the aspect of the chlorine lines for different pressures. The latest and most accurate measurements are by Eder and Valenta,[6] who used a Rowland grating and photographed almost the entire spectrum, finding about four hundred lines. The majority of these lines are in the ultra-violet or violet, but they extend through the blue and green into the yellow; and some, which Eder and Valenta observed but did not measure, are in the red. Those in the violet and ultra-violet are characterized as sharper than those in the green or yellow, the latter being, for the most part, broad or indistinct.

Investigations on the absorption spectrum of chlorine other than those already mentioned, do not appear to have been made, and in no case are measurements of the wave-lengths given. In a recent paper J. Koenigsberger,[7] referring to the effect of temperature on the line absorption of gases, speaks as if Brewster had investigated the absorption spectrum of chlorine, but he gives no exact reference. I have made careful search, but have been unable to find any work of Brewster's on the subject.

The study of the line absorption spectra of gases has received, on the whole, very little attention since the use of gratings has made possible more exact measurements. Considerable work has been done on the band absorption of liquids including the effect of temperature, etc. The influence of single solvents and of mixtures of solvents has also been investigated. There are some measurements on the absorption of vapors, but the apparatus used has been of low dispersive power, and the measurements are accordingly not very exact. The absorption of the various constituents of the air has been investigated and compared with the telluric lines of the solar spectrum, but few independent measurements of the wave-lengths have been made. From the reversal of emission lines, the absorption of hot vapors has been deduced. The work of Hasselberg[1] on the absorption of iodine and bromine is still the main example of an attempt to measure the lines in absorption spectra of gases under normal conditions as exactly as is done for emission spectra. This is is the more to be regretted as it is certain that a study of the line absorption spectra of gases in connection with emission spectra at low temperatures must increase our knowledge of the processes involved in both the emission and absorption of light, and aid us ultimately in picturing the constitution of the molecules. A further investigation of the absorption spectrum of chlorine seemed, therefore, not without interest, and the following pages give the details of some experiments on this subject.

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[1] *C. R.*, **73**, 369. [2] *Bull. de l'Acad. de St. Petersb.*, **28**, 405, 1881.

[3] LECOQ DE BOISBAUDRAN, *Spectres lumineux*, 1874.

[4] EUGEN DEMARCAY, *Spectres lumineux*, 1895.

[5] *Sitzungsb. d. kais. Akad. d. Wiss.*, Wien, **77**, 839, 1878; **78**, 4 Abth., 1878.

[6] *Denkschr. d. kais. Akad. d. Wiss.*, Wien, **68**, 1899.

[7] *Ann. der Phys.* [4], **4**, 806, 1901.

APPARATUS.

The physical laboratory at Bryn Mawr College is provided with a 15 ft. Rowland grating of 15,000 lines to the inch and a ruled surface of 11×4 cm, which is mounted after the usual Rowland method. The camera holds plates 30.5×3.5 cm, and is provided with the arrangement used by Rowland[2] for comparison spectra.

Plates made by C. S. Schleussner, of Frankfurt a. M., were used to photograph in the blue and violet, and Seed's orthochromatic plates or Cramer's isochromatic plates were used in the green and yellow. The developer used throughout the investigation was mixed after the formula given by L. E. Jewell.[1]

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[1] *Mem. de l'acad. de St. Petersb.*, 7, 36, No. 17, 1889; *K. Svenska Vet. akad. Handl.* No. 3, 24, 1891.

[2] *Phil. Mag.* [5], 27, 378.

In the green and yellow of the first order for slit width about 0.001 in. the time of exposure for the source alone, whether Sun or electric arc, was from six to ten minutes; with the tube of chlorine interposed it was from twenty to thirty minutes. In the second order and with slit width about 0.002 in. the exposures were about three times those given above.

On account of the large number of standard lines which it provides, the Sun is the most desirable source of light for this kind of work; but as the solar beam after entering the grating room from the heliostat traverses a distance of only 34 cm before falling on the slit, it was questionable whether this would admit a sufficiently long column of chlorine to produce the desired spectrum. The attempts of earlier investigators with columns of this length failed to show any traces of absorption lines; but as the apparatus at their disposal was so different from that here used it was thought worth while to make a trial. The result showed that this length of column was insufficient; there were suggestions of lines, but the absorption was too weak to make certain of the existence of lines without further confirmation.

A tube 65 cm long was then used with the arc as the source of light. Decided absorption lines appeared; but as increasing the column of chlorine promised to intensify the lines, a tube 1.37 meters long, the longest which could be placed between the condensing lens and the slit, was finally used. This tube was of glass of 5.2 cm internal diameter and was closed with plane glass plates. Metal caps screwed on to metal collars, which were cemented on to the outside of the tube, held the glass plates in place. Holes bored in the glass tube corresponding to similar ones in the collars, to which nipples were fitted, served as inlet and outlet for the chlorine; later, it was found better to allow the metal collars to project beyond the tube in order to avoid boring the glass, as the cementing on of the collars seemed to strain the glass to such an extent that boring a hole in it almost invariably caused cracking.

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[1] ASTROPHYSICAL JOURNAL, 11, 242, 1900.

An attempt was made to use this tube with the Sun as source of light by placing it between the slit and the grating; with large slit with 0.0007 in., a fairly good photograph was obtainable, but diminishing the slit-width increased the indistinctness of the lines until they became broad and fuzzy. This, doubtless, was due to the larger proportion of light reflected from the sides of the tube. Blackening the tube with lampblack did not overcome the difficulty sufficiently to make this method feasible.

Another tube for use with solar light was made of steel, 33.2 cm long and 1.6 cm internal diameter. It also was provided with caps which screwed over the ends and held on the glass plates. It was hoped that this would hold the gas under more than atmospheric pressure, and that the effect of a longer tube would be thus obtained. However, the first form of end and valve leaked under pressure, as no form of packing could be found which chlorine would not attack. The steel itself was attacked, as was expected, but the ferric chloride soon formed a layer over the surface and protected the rest in great measure; and since it is a solid its presence cannot invalidate the results. When, however, particles of the chloride fell on the glass ends they became very troublesome and necessitated the removal of the caps in order to clean the glass. This proceeding was attended with difficulties as a leak of chlorine through the cap stuck tube and cap together. After some ineffectual attempts to obviate these difficulties the scheme was abandoned for the time being.

It was then determined to utilize the space between the total reflecting prism and the condensing lens for the solar beam, which latter lens is in a metal tube projecting outside from the wall of the room. A glass tube 80 cm long and 5.3 cm internal diameter was made for use in this position. Distinct absorption lines were thus obtained; those towards the less refrangible end were still faint. Photographs were taken of all parts of the visible chlorine absorption spectrum from the D lines down, using both arc and Sun as the source of light.

To obtain the ultra-violet portion the glass ends were removed from the last-mentioned tube and were replaced by lead ones in which were inserted oblong quartz plates put in with soluble glass or soft wax. These were 2.5 × 4.0 cm, the largest possessed by the laboratory. For the extreme portion the Sun could not be used as a source of light, as the heliostat mirror at present in use is not of speculum metal, but of silvered glass, and the more refrangible rays are already absorbed. The arc was therefore used with a system of two quartz lenses.

The chlorine for these experiments was at first prepared from sulphuric acid, sodium chloride, and manganese dioxide in the usual way; that used later was taken from a cylinder of liquid chlorine, supplied by Messrs. Eimer and Amend, of New York, passed through washing and drying bottles and then led into the tubes. This cylinder gave a most convenient supply at any desired time, and the spectrum obtained with the chlorine from this source corresponded exactly with that obtained from the gas prepared by myself.

Further tests were made, however, for impurities which might cause errors in the results. As such, chlorine oxides were especially to be feared; but very careful tests showed that no trace of chlorine oxides was present. Carbon dioxide and a small fraction of air were found, the two making up in an extreme case one fourth of the total volume. Carbon dioxide has, however, no absorption in the visible part of the spectrum. P. Ballei[1] states that 75 meters of this gas under pressures up to twenty atmospheres showed no trace of an absorption spectrum; thus its presence, mixed in with the chlorine, but forming no chemical compound with it, can have no effect except to change the total pressure. The same is true for the small amount of air present.

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[1] *Nuovo Cimento*, 9, 172, 1899.

For assistance in making the analysis of the chlorine, my thanks are due to Dr. Kohler, professor of chemistry at Bryn Mawr College.

MEASUREMENTS.

The pitch of the screw of the dividing engine with which the plates were measured is approximately 1 mm; the head reads to 0.005 mm and the vernier to 0.001 mm. The errors of turn and of run of the screw were investigated before final measurements were made.

To determine a possible error in turn the distance along a given line between two fine lines drawn with a diamond point on steel, less than a tenth of a millimeter apart, was measured, starting from different positions of the head. For this purpose a microscope of magnifying power 35 was used. The variation in the readings was found to be not greater than the possible error of setting. The greatest deviation from the mean was 0.0015 mm and the average deviation was less than one half of this amount, or not more than 0.002 Å. U., when turned into wave-lengths. As the lines to be measured were not sufficiently sharply defined to attain to greater accuracy than this, no correction was applied.

The error in turn was examined over 15 cm of the screw, and found similarly to be negligible.

The microscope used for measuring the lines on the photographic plates had a magnifying power of 16. The wave-lengths were computed in the usual way from those of standard lines. The wave-lengths of all reference lines used were taken from Rowland's table of standard wave-lengths. On the arc plates there was some difficulty in obtaining standards, but sufficient were always found from which to calculate the reduction factor; other Rowland lines were sometimes used for com parison.

Both Sun and arc plates had their disadvantages. Even with the comparison solar spectrum photographed beside the solar plus the chlorine absorption spectrum, it is difficult to decide at times whether a line belongs to chlorine or not. If a line is so close to a solar line as to be inseparable from it, though its existence may be apparent from the broadening of the solar line, or from the increase of intensity, accurate setting is very difficult without some *a priori* knowledge of the width and character of the line. On the other hand, when the light from the glowing positive pole of the electric arc gives the spectrum the plates abound with black lines on a continuous dark background. The chlorine absorption lines appear, then, as white lines mixed in with black ones, and the danger arises of mistaking for an absorption line, the narrow space between two adjacent black lines, which is white merely by contrast. As a great number of photographs have been examined in this respect it is scarcely possible that any lines measured have been thus mistaken. There is the possibility that a chlorine line may fall on a black line, in which case it may not appear as an absorption line at all. Especially is this possible in a part of the green carbon band.

All of the lines given have been measured on arc plates, a large number have been measured also on Sun plates, as will be seen from the tables. As many of the lines are ill-defined, the second order plates did not offer much advantage over those of the first order, except for those lines which are broken up into doubles in the second order, and as the time of exposure in the second order was very much longer, the first order was used more extensively. In the first order 1 mm on a plate corresponds to 3.6 Å U., approximately.

The average mean error of measurement is about 0.015 Å. U. As stated above, the only exact measurements of this kind previously made are due to Hasselberg. He claims an accuracy of 0.02 or 0.03 Å. U. for his measurements on the sharpest lines of the absorption spectrum of iodine, lines which he used as normals; and as it is to be inferred that the lines of the bromine spectrum are less well-defined than those of iodine, the general accuracy is probably not so great for the measurements on the bromine spectrum. The error, then, in the present measurements is almost certainly less than that in previous work on absorption spectra, and is also not greater than that of the general measurements on emission spectra.

Explanation of Table I.—The measurements are given in the following table. The first column contains the number of separate measurements on the line; an *s* after the number indicates that some of the measurements were made on Sun plates. The second column contains the wave-length in Ångström units; the third, the mean error; and the fourth the intensities, reckoned on the scale 0, 1, 2, . . . 10, and details as to the appearance of the lines. Intensity 1 is given to the faintest lines that are clearly visible; 0 to lines that are not so; and 10 to the strongest lines.

N signifies ill-defined; *s*, sharp; *b*, broad; *vb*, very broad; *d*, double; *d?*, possibly double. From λ 4799 to λ 5165 the numbers are given for chlorine at one atmosphere pressure. From λ 5165 to λ 5218 measurements and intensities are given for a meter of chlorine both at atmospheric pressure, and at a pressure of two and a half atmospheres; from λ 5218 on the measurements are for a pressure of two and a half atmospheres.

TABLE I.

n	Wave-length	Mean error	Intensity and character	*n*	Wave-length	Mean error	Intensity and character
3	4799.11	0.017	0 *N*	6 *s*	4833.83	0.015	2 *N d*
4	4799.951	.011	0	6 *s*	4834.263	.010	2
3	4800.95	.015	0	4 *s*	4834.729	.012	2
4	4802.066	.011	0	8 *s*	4835.205	.007	4
3	4802.759	.011	0	5 *s*	4835.79	.018	3 *N*
6	4803.322	.013	1	5 *s*	4836.495	.014	4 *N*
3	4804.560	.023	0	9 *s*	4837.073	.006	4 *d?*
2	4805.13	.037	0	4 *s*	4837.54	.016	1
4	4805.94	.029	0	7 *s*	4838.02	.016	7 *b*
5	4806.57	.014	2	4	4838.94	.012	3
5	4807.081	.011	2	6 *s*	4839.435	.013	2
2	4807.38	.003	0	4	4839.85	.018	2 *N*
5	4809.081	.012	2	3	4840.31	.006	1 *N*
3	4809.66	.012	1	5 *s*	4840.973	.012	10
4	4809.949	.021	1	3 *s*	4841.41	.012	1
4	4810.603	.014	3	3 *s*	4841.667	.004	2
8 *s*	4811.168	.006	4	2	4841.96	.043	2 *N*
5 *s*	4811.899	.013	3	3	4842.93	.026	3 *b*
4	4812.598	.010	2 *N*	2	4843.21	.011	2
5 *s*	4813.047	.013	2 *N*	3	4843.71	.010	2
4	4813.747	.003	3 *N b*	2	4844.10	.020	2 *N*
6 *s*	4814.393	.008	3 *N b*	5 *s*	4844.601	.012	2 *N*
4	4814.77	.030	0	7 *s*	4845.209	.008	5 *b*
8 *s*	4815.353	.008	2 *b*	5 *s*	4846.017	.009	3
7 *s*	4815.832	.014	2 *b*	8 *s*	4846.534	.005	6
3	4816.43	.019	0	3 *s*	4847.13	.004	0
3	4816.77	.003	0	7 *s*	4847.736	.010	3 *N*
2	4817.44	.016	1 *N*	3	4848.49	.022	2
4	4817.927	.009	4	5 *s*	4849.122	.006	3 *b*
3	4818.34	.026	1	4 *s*	4849.647	.006	1
4 *s*	4818.75	.021	2	9 *s*	4850.141	.007	3 *N*
6 *s*	4819.15	.028	1 *b N*	9 *s*	4850.605	.009	3 *N*
4 *s*	4820.059	.011	2 *N*	9 *s*	4851.062	.007	3 *N*
3	4820.45	.022	2 *N*	4	4851.637	.007	1 *N*
4	4821.08	.014	3 *N*	7 *s*	4852.158	.009	5
7 *s*	4821.955	.012	2 *b*	6 *s*	4852.532	.008	2
6 *s*	4822.652	.009	2 *b N d?*	7 *s*	4853.30	.011	3 *d*
2	4823.22	.022	2 *N*	4	4853.99	.015	1 *N*
3	4823.69	.018	2 *N*	9 *s*	4854.411	.008	4
3	4824.21	.016	2 *b N*	4	4855.070	.011	1 *N*
8 *s*	4824.735	.007	2	5	4855.595	.012	8 *s*
5 *s*	4825.888	.013	4 *vb*	4	4855.96	.010	1
8 *s*	4826.887	.011	4 *b*	4 *s*	4956.647	.001	2
5 *s*	4827.630	.008	4 *b d?*	6 *s*	4856.066	.016	2
6 *s*	4828.614	.012	4 *b*	3 *s*	4857.30	.023	1 *N*
4	4829.41	.018	3	6 *s*	4857.867	.010	9 *s*
6 *s*	4830.068	.011	3 *b*	4 *s*	4858.39	.016	1
8 *s*	4830.418	.005	3 *b*	4 *s*	4858.763	.008	1
3	4831.315	.003	3 *vb d*	4	4859.173	.010	5 *b*
5 *s*	4832.057	.009	2	6 *s*	4859.761	.012	5 *b*
4 *s*	4832.67	.020	3 *N*	3	4860.37	.013	2 *d?*
3	4833.13	.036	1	3 *s*	4860.84	.021	2 *N*

TABLE I—*Continued.*

n	Wave-length	Mean error	Intensity and character	*n*	Wave-length	Mean error	Intensity and character
4	4861.472	0.005	6	4	4888.63	0.016	2 *N*
4	4861.985	.014	2 *N*	5	4888.966	.012	4 *b*
3	4862.34	.019	2 *N*	4 *s*	4889.851	.007	1
8 *s*	4863.126	.008	5 *b*	5 *s*	4890.23	.019	2 *N*
4	4863.36	.011	1	5 *s*	4890.503	.009	2 *N*
5	4864.127	.004	5 *b d ?*	3 *s*	4891.05	.031	0
6	4864.991	.011	5 *b d*	3	4891.42	.014	2 *N*
3	4865.78	.023	0	4	4891.829	.013	3 *s*
4 *s*	4866.118	.016	2	2	4892.20	.002	0
4	4866.625	.007	6	2	4892.40	.018	0
5 *s*	4867.331	.006	3 *b*	4 *s*	4892.801	.006	2
4	4867.796	.010	1 *b N*	3	4893.11	.033	1 *N*
6	4868.499	.007	10	3	4893.52	.026	2 *N*
4	4868.90	.011	1	8 *s*	4893.695	.010	3 *N*
4 *s*	4869.83	.022	4 *b N*	4 *s*	4894.20	.021	1 *N*
4	4870.398	.009	4 *b*	4 *s*	4894.49	.022	1 *N d*
5	4871.123	.006	7 *b*	3	4894.77	.043	0
3	4872.19	.037	2 *N*	8 *s*	4895.317	.008	4 *b*
4	4872.526	.008	3 *N*	3	4895.69	.017	0
4	4873.11	.018	2 *N*	9 *s*	4895.950	.011	4 *b N*
5	4873.60	.018	2 *N*	4	4896.35	.021	2 *N*
3	4874.088	.006	3 *b N*	4	4896.888	.007	2
4 *s*	4874.650	.010	4	4 *s*	4897.119	.009	3
3 *s*	4875.19	.024	2 *b*	8 *s*	4897.572	.011	4 *b*
4	4875.801	.016	4	3	4897.75	.017	3 *N*
4	4876.180	.003	3	5 *s*	4898.285	.014	2
4	4876.509	.008	3	3 *s*	4899.218	.008	2 *b N*
4	4876.871	.002	3	3 *s*	4899.45	.020	2 *N*
7 *s*	4877.331	.010	4 *b*	7	4899.991	.011	4
2	4877.92	.009	4 *b N*	4	4900.41	.018	2 *N*
4	4878.15	.023	4 *vb*	6 *s*	4901.074	.006	3 *N*
4 *s*	4878.869	.012	4	4 *s*	4901.366	.010	2
4 *s*	4879.124	.012	4	4 *s*	4901.61	.016	2 *b N*
5 *s*	4879.777	.012	1	11 *s*	4902.465	.007	6 *s*
3 *s*	4880.11	.042	1	7	4903.10	.019	2 *N*
5 *s*	4880.452	.014	2	5	4903.57	.022	4 *N*
5 *s*	4881.060	.012	4 *b*	8 *s*	4904.304	.005	4 *s*
3 *s*	4881.45	.021	3	5	4904.767	.011	1 *N*
3	4882.00	.012	2	7	4905.275	.013	4
2	4882.23	.004	2	9 *s*	4905.702	.009	4
3 *s*	4882.84	.029	3 *N*	5 *s*	4906.40	.024	0
3 *s*	4883.12	.027	3 *N*	7	4906.782	.013	0
3 *s*	4883.47	.007	1	7 *s*	4907.383	.011	6
4	4883.94	.016	2 *N*	6	4907.830	.012	1
3 *s*	4884.46	.042	1	5	4908.315	.009	3 *s*
4 *s*	4884.874	.005	4 *b*	5 *s*	4908.913	.009	2 *b d ?*
4 *s*	4885.112	.018	4	3	4909.796	.004	4
4	4885.737	.008	1	3	4910.155	.001	4
4	4886.03	.018	1	2	4910.49	.057	0
4	4887.08	.014	2 *b d*	4	4911.14	.015	1
4	4887.543	.008	3 *s*	5 *s*	4911.715	.013	4
4	4888.05	.027	1	4	4912.15	.022	4

TABLE I — *Continued.*

n	Wave-length	Mean error	Intensity and character	*n*	Wave-length	Mean error	Intensity and character
5 *s*	4912.744	0.008	1	4 *s*	4942.375	0.009	4
4 *s*	4913.060	.007	1	5 *s*	4942.905	.016	4
7 *s*	4913.433	.009	4	7 *s*	4943.703	.009	3 *N*
4	4914.089	.011	1	6 *s*	4944.338	.009	3 *b d ?*
4	4914.50	.019	1	18 *s*	4945.031	.004	6 *s*
6 *s*	4915.058	.012	3	4	4945.531	.018	4
5 *s*	4915.394	.015	2	3	4946.39	.027	4 *b*
6 *s*	4915.977	.009	2 *N*	7 *s*	4947.287	.006	4
6 *s*	4916.408	.010	2	7 *s*	4947.804	.007	5
7 *s*	4916.868	.013	2 *N*	4 *s*	4948.439	.003	1
4	4917.33	.017	2 *N*	3 *s*	4949.01	.026	1
6 *s*	4917.943	.011	7	2	4949.48	.002	1 *N*
4	4918.52	.018	1 *N*	3 *s*	4949.97	.018	2 *N*
3	4919.07	.007	1 *N*	2	4950.44	.006	1 *N*
3	4919.92	.024	3	4 *s*	4951.06	.016	4 *N* triplet?
3	4920.33	.006	2	4 *s*	4951.67	.026	2 *N*
3	4920.88	.029	2 *N*	2	4952.21	.002	2 *N*
5	4921.448	.006	4	2	4952.65	.018	2 *N*
4	4921.984	.015	4	4	4953.32	.017	6 *b*
2	4922.52	.011	2	3	4953.77	.018	0
4 *s*	4923.012	.010	2	6 *s*	4954.31	.018	4 broadened on red side
5 *s*	4923.530	.011	4				
2	4924.28	.010	4	4	4954.93	.017	4
3	4924.86	.019	3	2	4955.54	.005	1
2	4925.74	.030	2 *N*	4 *s*	4956.02	.018	3 *N*
3 *s*	4926.49	.004	2 *bN*	5 *s*	4956.477	.013	2
8 *s*	4927.213	.008	3	2	4956.79	011	1
2 *s*	4927.69	.009	0	3	4957.10	.017	2
6	4928.149	.009	5	2	4957.62	.018	2
7 *s*	4928.796	.008	4 *b*	5 *s*	4958.204	.007	3
9 *s*	4929.547	.009	5 *b*	18 *s*	4958.736	.004	4 *s*
5	4930.397	.018	5 *b*	4 *s*	4959.366	.011	3
6 *s*	4931.144	.007	5	4 *s*	4960.13	.023	3 *b N*
2	4931.47	.015	0	5 *s*	4960.767	.008	4
2	4932.11	.016	1	3 *s*	4961.33	.013	1 *N*
6 *s*	4932.85	.019	4	3	4961.987	.003	2 *b*
3	4933.86	.013	1 *b d N*	2	4962.74	.019	3
5 *s*	4934.77	.012	2 *b N*	5 *s*	4963.277	.009	3
4 *s*	4935.123	.014	2 *N*	4 *s*	4964.233	.009	4 *b d*
4 *s*	4935.583	.010	2 *N*	3 *s*	4964.872	.014	2
4	4935.85	.017	3	4 *s*	4965.535	.012	4 *b d*
5 *s*	4936.339	.009	2	2	4966.11	.030	0
6 *s*	4936.695	.015	5	3 *s*	4966.597	.012	4
4	4937.20	.010	2	5 *s*	4966.977	.011	4
4 *s*	4937.727	.017	2	2	4967.81	.020	1
3	4938.61	.018	2 *N* haze	2	4968.24	.044	4 *N*
3	4939.03	.016	2 haze	3	4968.99	.009	2
3	4939.60	.011	2 *N*	7 *s*	4969.533	.009	6 *b*
4	4940.11	.020	2 *N*	2	4970.06	.023	2
7 *s*	4940.655	.007	4	3 *s*	4970.522	.013	6 *b*
4 *s*	4941.290	010	2	2	4970.89	.037	2 *N*
6 *s*	4941.830	.013	4 *b*	2	4971.69	.002	2

TABLE I — *Continued.*

n	Wave-length	Mean error	Intensity and character	*n*	Wave-length	Mean error	Intensity and character
5 *s*	4972.252	0.007	4	2	5004.11	0.021	2
2	4972.77	.004	2	2	5004.95	.012	2 *N*
4 *s*	4973.264	.011	5	4 *s*	5005.34	.024	4 *N*
4	4974.294	.009	4 *N*	2	5006.25	.007	2
5	4974.912	.007	4 *s*	4 *s*	5006.92	.025	2 *N*
3	4975.48	.029	2 *b N*	4 *s*	5007.685	.010	3 *b N*
2	4976.54	.007	1 *N*	5 *s*	5008.594	.015	5 *v b*
5 *s*	4976.943	.014	2 *N*	2	5009.32	.018	1 *b N*
2	4977.43	.092	0 *N*	2	5009.81	.021	2 *N*
2	4978.211	.003	6	2	5010.154	.004	4
2	4978.76	.042	2 *b N*	2	5010.64	.100	0 *N*
2	4979.76	.019	3 *N d?*	2	5011.20	.011	1
2	4980.42	.017	7	4 *s*	5011.637	.010	1
5 *s*	4981.114	.009	4	4	5012.104	.005	8 *s*
3	4981.67	.021	8	2	5012.78	.024	2 *N*
4 *s*	4982.337	.004	4	3	5013.59	.005	1 *b N*
2	4982.70	.001	2	2	5014.06	.025	1
3	4983.14	.015	2	3	5014.47	.016	4 *b*
2	4984.31	.019	5 *N*	2	5014.70	.050	0
2	4984.75	.017	0	3	5015.13	.021	2
2	4985.16	.009	3	5 *s*	5015.740	.007	4
3	4985.71	.008	3	2	5016.55	.031	5 *N*
3	4986.23	.020	5	2	5016.96	.030	3
5 *s*	4987.18	.015	2 *b*	2	5017.42	.029	0
5 *s*	4987.854	.008	3	3	5017.69	.024	5
3 *s*	4988.165	.012	2	2	5018.60	.019	3
5 *s*	4988.576	.011	6 *s*	2	5018.95	.013	3
2	4989.06	.022	1	5 *s*	5019.425	.009	6
2	4989.55	.003	3	2	5020.49	.038	4 *vb d?*
3 *s*	4989.906	.010	3	5 *s*	5021.313	.016	4
4 *s*	4990.408	.011	4	2	5021.67	.015	1
4	4991.371	.010	7 *b*	2	5022.05	.025	2 *N*
4 *s*	4991.993	.015	4 *N*	2	5022.30	.014	2 *N*
6 *s*	4992.757	.012	6	2	5022.79	.014	4 *N*
3	4993.62	.033	5	2	5023.064	.002	4 *N*
2	4994.17	.017	2	3 *s*	5023.499	.012	5
4 *s*	4994.809	.004	5 *N*	2	5024.12	.017	1
6 *s*	4995.465	.007	3	5 *s*	5024.592	.008	5
4 *s*	4995.914	.023	5 *N*	2	5024.95	.002	5
3 *s*	4996.193	.003	5	2	5025.54	.017	1
3 *s*	4996.544	.010	2	2	5025.816	.002	3
2	4997.28	.007	1 *N*	2	5026.29	.002	1
5 *s*	4997.824	.010	4 *vb*	2	5026.66	.011	2 *b N*
7 *s*	4998.805	.010	8	3	5027.19	.010	2 *N*
4	4999.471	.017	2	3	5027.52	.016	2 *N*
4 *s*	4999.993	.017	2	3	5028.426	.005	2 *N*
4	5000.917	.013	2	2	5028.775	002	2 *N*
3	5001.38	.015	2	3 *s*	5029.235	.013	2
2	5002.04	.013	2 *b*	2	5029.87	.004	6
2	5002.75	.011	0	2	5030.22	.010	1
5 *s*	5003.359	.014	4 *b*	3 *s*	5030.657	.011	3
2 *s*	5003.61	.021	3	2	5031.11	.060	0 haze

TABLE I—*Continued.*

n	Wave-length	Mean error	Intensity and character	*n*	Wave-length	Mean error	Intensity and character
2	5031.46	0.008	2 *N*	3	5059.47	0.017	1
2	5031.90	.012	1 *N*	4	5059.800	.014	2
2	5032.42	.013	3	3	5060.56	.006	2 *N*
3 *s*	5032.87	.020	3 *N*	6 *s*	5061.383	.011	5 *b*
2	5033.566	.001	2	2	5062.20	.002	1 *b N*
3 *s*	5033.89	.009	2 *N*	2	5062.89	.004	1 *b N*
4 *s*	5034.541	.009	3	2	5064.08	.027	1 *N*
2	5034.89	.012	3	2	5064.49	.024	3
3	5035.50	.031	3	3	5065.39	.025	3
3	5036.07	.014	3	4 *s*	5066.110	.010	4 *s*
3	5036.77	.023	4	3	5066.65	.017	2 *N*
2	5037.19	.009	0	3	5067.23	.034	1 *N*
3	5037.56	.021	1	2	5067.86	.014	1 *N*
5 *s*	5038.028	.014	5	2	5069.11	.053	2 *vb N*
2	5038.57	.010	2 *N*	2	5069.60	.021	2 *N*
2	5039.35	.030	2	2	5070.59	.003	2 *N*
3 *s*	5039.824	.017	5	2	5071.45	.020	3
2	5040.17	.034	2	2	5071.90	.033	0 *N*
3 *s*	5040.746	.009	4 *s*	3	5072.46	.016	3 *b N*
2	5041.28	.014	2	2	5073.29	.014	1
2	5041.56	.030	2	2	5073.61	.030	0
2	5042.46	.001	1 *vb d? N*	3	5073.99	.007	2
2	5043.48	.034	1 *b N*	2	5074.65	.015	2 *b N*
3	5044.38	.018	2	2	5075.38	.008	3
4 *s*	5045.061	.010	3	2	5076.08	.023	3
4 *s*	5045.500	.012	3	2	5076.54	.015	3
2	5046.02	.014	1 *N*	2	5077.06	.015	2
2	5046.62	.036	0	6 *s*	5077.434	.009	5
3 *s*	5047.22	.014	3	2	5078.01	.009	1
3 *s*	5047.78	.012	2	4 *s*	5078.543	.012	4
3	5048.24	.012	3	2	5079.08	.018	1
2	5048.94	.008	4	2	5079.57	.006	6 *s*
3	5049.33	.019	2	2	5080.39	.005	2
2	5049.68	.002	2 *N*	2	5080.78	.015	2
2	5050.05	.022	2 *N*	2	5081.69	.007	1 *b N*
2	5050.71	.003	3	2	5082.28	.008	1 *b N*
2	5051.01	.011	3	2	5082.83	.009	2
2	5051.48	.016	2	2	5083.50	.008	1 *b*
3	5051.87	.010	4	2	5084.15	.010	4
2	5052.33	.012	3	2	5084.78	.012	2
2	5052.65	.006	3	2	5085.62	.040	0
2	5053.15	.009	2 *N*	2	5086.25	.001	3
2	5053.650	.000	2 *N*	2	5086.95	.027	1
3 *s*	5054.21	.023	3	1	5087.22		2
2	5054.60	.015	2 *N*	2	5087.93	.035	2 *b N*
2	5055.18	.032	3	2	5088.72	.018	3 *vb d*
2	5055.59	.014	2 *N*	2	5089.53	.004	2
2	5056.36	.013	3	4 *s*	5090.416	.006	4
2	5056.93	.035	3	2	5091.10	.007	1
6 *s*	5057.519	.012	4 *b*	2	5091.58	.001	0
3	5058.08	.026	1	3	5092.17	.024	2 *N*
6 *s*	5058.647	.009	4 *b*	2	5092.86	.033	2 *N*

TABLE I — *Continued.*

n	Wave-length	Mean error	Intensity and character	*n*	Wave-length	Mean error	Intensity and character
2	5093.39	0.010	1	2	5122.13	0.025	1
4 *s*	5093.962	.004	3	2	5122.72	.010	1 *N*
2	5094.755	.003	3 *vb*	2	5123.38	.072	1 *b N*
2	5095.86	.028	4	2	5124.57	.002	2 *N*
2	5096.22	.025	1 haze	2	5125.11	.008	2 *N*
2	5096.68	.005	1 haze	2	5125.93	.014	1
3	5097.22	.017	2	2	5126.38	.038	0 *N*
3	5097.66	.022	2 *N*	3	5126.89	.015	3
3	5098.22	.009	2	3	5127.51	.012	2
2	5098.75	.005	2 *N*	2	5128.08	.027	3 *s*
2	5099.05	.025	2 *N*	2	5128.45	.003	1
2	5099.53	.008	1 *N*	3	5128.94	.008	3 *s*
2	5099.86	.011	1 *N*	3	5129.59	.013	2
3	5100.27	.026	2	3	5130.35	.022	2 *b N*
2	5100.77	.057	1 *N*	4	5131.327	.012	8
2	5101.12	.017	3	2	5131.95	.001	2 *N*
5 *s*	5101.85	.017	3	4	5132.240	.014	2 *N*
2	5102.55	.035	1 *N*	2	5132.864	.001	1
3	5102.86	.018	2 *N*	5 *s*	5133.372	.013	4
2	5103.31	.040	0	3	5134.52	.021	2 *vb N*
2	5104.06	.023	2	4 *s*	5135.765	.015	5
3 *s*	5105.15	.024	4 *b*	5	5136.95	.023	3 *N*
2	5105.915	.002	3	2	5137.51	.025	0
3	5106.21	.015	4	5	5138.173	.012	3 *vb*
2	5107.26	.009	4 *b d?*	5	5139.15	.019	4 *b*
2	5108.33	.038	5	4	5139.81	.017	3
2	5108.77	.006	0	3	5140.61	.026	3 *b N*
2	5109.15	.008	0	4	5141.08	.017	2 *N*
2	5109.69	.002	4	3	5141.71	.012	2
2	5110.07	.013	4	2	5142.45	.026	2 *N*
2	5110.61	.005	2	2	5142.75	.033	2 *N*
2	5111.13	.023	1 *N*	5	5143.283	.014	2
2	5111.54	.022	2 *N*	2	5143.69	.027	1 *N*
2	5112.11	.004	2	5	5144.372	.013	4 *vb*
2	5112.66	.030	1	2	5145.32	.004	0
2	5113.08	.016	2	6	5146.027	.010	4 *b*
2	5113.49	.014	2	6	5146.741	.015	3
2	5113.87	.002	1	6	5147.597	.009	4 *b*
2	5114.24	.006	1	2	5148.69	.015	0
2	5114.66	.005	1	7	5149.531	.010	2 *N*
2	5114.97	.004	1	3	5150.56	.010	1
2	5115.81	.018	1 *N*	2	5151.12	.006	4
3	5116.22	.004	1 *N*	2	5151.34	.020	4
3	5116.60	.005	1 *N*	5	5151.81	.010	0
2	5117.40	.036	4 *b*	6	5152.421	.008	4
2	5117.85	.008	4 *b*	6	5153.042	.015	3
2	5118.69	.024	0 *N*	4	5153.712	.012	2
2	5119.24	.011	4	5	5154.22	.018	2 *N*
2	5119.78	.007	4	4	5154.955	.013	4 *N*
2	5120.45	.011	0	4	5155.38	.021	2 *b N*
2	5121.07	.009	4	2	5156.33	.022	2 *b*
2	5121.46	.067	0 *N*	5	5157.059	.012	4 *N*

TABLE I — *Continued.*

n	Wave-length	Mean error	Intensity and character	*n*	Wave-length	Mean error	Intensity and character
5	5157.553	0.013	3 *N*	4	5161.67	0.026	2
3	5158.19	.027	1	5	5162.37	.021	1 *N*
4	5158.52	.019	4	6	5162.99	.016	7
6	5159.113	.011	4	3	5163.40	.011	0
2	5159.75	.006	0	5	5163.948	.010	3
3	5160.53	.013	0	5	5164.954	.015	3
3	5161.20	.022	1 *N*				
Chlorine at atmospheric pressure				Chlorine at a pressure of 2½ atmospheres			
3	5165.584	.015	2	3	5165.596	.012	3
3	5165.987	.008	2	4	5166.002	.016	3
4	5166.396	.005	2	2	5166.428	.015	3
5	5167.255	.007	5 *vb*	5	5167.268	.010	10 *vb*
11	5168.426	.006	6 *s*	8	5168.427	.005	9 *s*
3	5168.821	.013	1 *N*				
3	5169.733	.008	5 *b*	6	5169.727	.008	10 *b*
3	5170.998	.015	2 *vb N*	4	5171.008	.022	5 *b*
4	5172.014	.013	3	5	5172.039	.007	3
3	5172.419	.005	3	4	5172.461	.013	3
3	5172.91	.017	0				
4	5173.437	.013	2	6	5173.433	.008	2
4	5173.946	.010	2	6	5173.947	.013	2
4	5174.741	.016	1 *vb N*	4	5174.756	.018	2 *b*
4	5175.499	.008	4 *s*	5	5175.515	.015	5 *s*
3	5176.142	.008	4	6	5176.149	.008	5
2	5177.109	.003	3	4	5177.142	.014	4
3	5177.615	.009	2 *N*	3	5177.618	.015	4
3	5178.30	.029	0				
4	5178.780	.015	6 broadened on red side	6	5178.818	.005	7 *b*
3	5179.197	.031	0 haze	3	5179.375	.027	1 band
3	5179.692	.029	0 haze				
4	5180.550	.019	3 *b N* broadened on red side	4	5180.612	.010	5 *b*
1	5181.101		0 *N*	3	5181.074	.022	1 *N*
3	5181.619	.007	0	3	5181.631	.009	1
3	5182.379	.018	3 *b N* broadened on red side	6	5182.413	.012	7
3	5182.927	.010	0 *N*	1	5182.914		1 *N*
2	5183.408	.003	0 *N*	1	5183.366		1 *N*
3	5184.244	.022	3 *b N* broadened on red side	6	5184.300	.013	8
3	5184.555	.014	0				
4	5184.999	.024	1	4	5185.014	.020	1
4	5185.579	.006	1				
4	5186.142	.011	8	6	5186.181	.006	10
3	5186.517	.007	0	1	5186.528		0
3	5187.271	.017	2 *b*	3	5187.328	.020	2 *b*
3	5188.158	.021	3 *b*	3	5188.122	.012	6 *b*
4	5189.028	.019	1 *b*	6	5189.024	.016	2

TABLE I—*Continued.*

Chlorine at atmospheric pressure				Chlorine at a pressure of 2½ atmospheres			
n	Wave-length	Mean error	Intensity and character	*n*	Wave-length	Mean error	Intensity and character
3	5189.862	0.026	1 *N*	3	5189.894	0.013	1 *N*
3	5190.314	.004	1 *N*	4	5190.285	.025	1 *N*
2	5190.816	.013	0 *N*	4	5190.826	.030	0 *N*
3	5191.395	.005	1	4	5191.495	.016	2
3	5191.964	.007	1	5	5191.928	.015	2
3	5192.533	.003	3	6	5192.536	.011	4
3	5193.540	.011	2 *b*	5	5193.512	.010	3 *b*
2	5194.158	.013	2	4	5194.154	.012	2
4	5194.706	.013	5	5	5194.751	.014	8
2	5195.444	.006	2	4	5195.452	.014	2
3	5196.220	.018	5 *s*	6	5196.219	.011	6 *s*
2	5196.916	.031	3 *N*	6	5196.913	.017	4 *N*
2	5197.320	.010	1 *N*	2	5197.340	.005	1 *N*
2	5197.839	.008	1	3	5197.906	.011	2
2	5198.314	.003	1 *N*	2	5198.300	.015	1 *N*
3	5198.832	027	1 *s*	6	5198.841	.011	7 *s*
				3	5199.465	.019	3
3	5199.836	.009	3 *N*	4	5199.854	.011	6
3	5200.625	.018	2 *N*	1	5200.648		4
3	5201.076	.014	2 *N*	1	5201.012		4
3	5202.108	.017	3 *vb*	3	5202.073	.018	6 *vb*
3	5203.150	.010	4 *b*	3	5203.166	.015	8 *b*
2	5204.414	.020	4 *b*	4	5204.407	.010	10 *b*
3	5205.722	.018	2 *vb*	4	5205.729	.026	5 *b*
3	5207.113	.043	2 *vb*	4	5207.100	.005	5 *vb*
3	5207.915	.013	1	4	5207.942	.011	2
				3	5208.479	.040	0
3	5209.423	.020	2	3	5209.440	.029	3
2	5210.188	.014	1 *N*	3	5210.186	.010	2 *N*
				4	5210.754	.018	2 *b N*
2	5211.677	.043	1 *N*	4	5211.703	.016	2
3	5212.537	.017	0 *N*	3	5212.355	.019	2
1	5213.13		1 *N*	4	5213.348	.014	3 *bd N*
2	5213.491	.006	1 *N*				
2	5214.998	.058	1 *N*	2	5214.051	.046	2 *b N*
2	5215.896	.028	1 *N*	4	5215.892	.019	2
2	5216.886	.050	2 *b N*	4	5216.917	.009	5 *b*
1	5217.899		1	4	5217.874	.012	2
2	5218.783	.009	2 *b*	4	5218.755	.017	5 *b*

Chlorine at 2½ Atmospheres Pressure.

6	5219.715	.016	1	5	5227.316	.013	2
5	5220.696	.010	10	5	5227.73	.016	1 *N*
6	5221.72	.015	2	5	5228.63	.025	3
4	5222.73	.019	5 *b*	5	5229.105	.010	2
4	5223.87	.008	1 *b N*	5	5230.051	.010	3 *b N*
4	5224.62	.035	3 *vb N*	5	5230.61	.025	1 *N*
4	5225.40	.017	1	5	5231.16	.025	1 *N*
5	5226.37	.021	3 *vb*				

TABLE I — *Continued*

Chlorine at 2½ atmospheres pressure.

n	Wave-length	Mean error	Intensity and character
3	5231.55	0.028	0
7	5232.12	.02	2
5	5233.37	.010	6 broadened on red side
2	5233.74	.025	2
5	5234.693	.006	7 *s*
5	5236.324	.011	4 *b*
5	5237.309	.006	5
4	5238.16	.018	4 *b d* ?
7	5239.05	.014	1
4	5240.15	.024	2 *N*
5	5240.55	.014	2 *N*
3	5241.41	.018	0
6	5241.697	.019	3 *b*
6	5242.518	.011	2
5	5242.939	.014	3
5	5244.151	.029	1 *b N*
7	5245.110	.010	3 *s*
6	5245.673	.012	2 *s*
5	5246.47	.028	1 *N*
5	5247.13	.022	1 *N*
6	5247.936	.010	3
5	5248.635	.009	5 *b*
5	5249.527	.014	1
6	5250.061	.013	4
5	5250.72	.019	0
5	5251.13	.032	1
4	5251.72	.016	2
5	5252.26	.015	1
5	5253.282	.008	3 broadened on red side
5	5254.606	.016	3 *b*
5	5256.26	.023	1
5	5257.08	.019	3
3	5257.41	.005	1
6	5258.166	.015	4 *s*
5	5258.882	.013	4 *b*
6	5260.088	.009	4
7	5260.584	.009	4
3	5261.79	.024	1 *N*
5	5262.068	.010	3
4	5262.640	.012	2
5	5263.376	.007	3
5	5263.82	.023	2 *N*
4	5264.77	.040	1 *vb N*
4	5265.73	.037	0
5	5266.310	.010	1
4	5266.96	.023	2 *N*
4	5267.46	.016	2 *N*
4	5268.517	.006	2 *N*
4	5268.98	.022	2 *N*
4	5269.44	0.020	1
4	5270.09	.021	1 *N*
4	5270.808	.009	2 *N*
5	5271.408	.012	2 *N*
2	5272.20	.008	0
4	5273.04	.023	3 *N*
4	5273.60	.023	0
4	5274.27	.026	0
3	5274.67	.040	0 *N*
5	5275.27	.020	2 *N*
5	5276.05	.022	1
5	5276.653	.015	4
6	5277.342	.014	4 *s*
7	5278.040	.008	4
7	5278.962	.013	1
4	5279.80	.015	2 *b*
4	5280.38	.019	2 *N*
5	5280.981	.006	2 *N*
4	5281.32	.024	1 *N*
4	5282.091	.011	3
5	5282.549	.012	2
4	5283.249	.012	2
4	5283.70	.015	3
4	5284.39	.020	2 *N*
4	5284.86	.018	2 *N*
3	5285.63	.010	0
3	5286.22	.014	1
4	5286.94	.056	0 *N*
4	5287.53	.023	2 *N*
4	5288.25	.023	1
5	5288.898	.012	3
5	5289.62	.019	2
5	5290.342	.007	5 *s*
5	5291.131	.008	1
6	5291.863	.008	4
5	5292.701	.009	1
4	5293.522	.010	4
4	5294.48	.020	1 *b*
5	5295.268	.012	4
5	5296.11	.022	0
6	5296.97	.016	4
5	5297.92	.019	1 *b*
4	5298.75	.017	1 *b*
5	5299.60	.014	2
4	5300.65	.020	4 *b N*
3	5301.50	.015	1
3	5302.48	.018	1 *b N*
3	5303.02	.064	1 *b N*
3	5304.69	.018	1 band
3	5306.90	.024	1 *N*
3	5307.49	.055	1 *vb N*

TABLE I — *Continued.*

Chlorine at 2½ atmospheres pressure

n	Wave-length	Mean error	Intensity and character	*n*	Wave-length	Mean error	Intensity and character
2	5307.90	0.046	0 *N*	4	5346.70	0.021	2
3	5308.43	.027	0 *N*	4	5347.40	.016	1
4	5308.99	.017	1	4	5347.960	.006	1
4	5309.62	.017	0	4	5348.702	.013	2
3	5310.11	.018	2	4	5349.556	.005	1
5	5310.958	.013	2 *s*	4	5350.48	.043	0 *N*
4	5311.718	.013	3 *s*	4	5351.63	.021	1 *N*
4	5312.57	.033	0 *N*	4	5352.650	.011	1 *b*
4	5313.42	.025	1 *N*	4	5353.878	.014	1 *b*
4	5314.13	.016	2	4	5355.04	.021	1 *b*
4	5315.074	.005	1	4	5355.98	.022	1
4	5315.63	.026	1	5	5356.76	.016	1
2	5316.36	.043	0	3	5357.29	.017	1
3	5316.66	.011	1	4	5357.52	.022	1
2	5317.28	.005	0	3	5358.25	.020	1 *N d*
4	5317.968	.013	1	4	5359.02	.018	1 *N*
3	5318.44	.029	0	5	5359.476	.007	1
4	5319.17	.014	1	4	5360.38	.016	2 *vb*
3	5319.78	.016	1	5	5361.88	.022	1 *vb N*
3	5320.55	.025	3	5	5363.58	.032	1 *b N*
3	5320.89	.020	3	5	5365.03	.010	1
4	5322.19	.017	3 *b d?*	4	5366.05	.009	0
2	5322.76	.017	0	5	5366.71	.021	1
4	5323.608	.010	4 *b*	3	5367.43	.015	0
4	5324.42	.014	0	2	5367.98	.003	0
4	5325.18	.018	1	4	5368.575	.006	1
4	5326.721	.010	3	2	5369.667	.012	0
4	5327 49	.023	1 *b*	4	5370.18	.022	0
4	5328.438	.014	4	4	5370.64	.053	1 *N*
4	5330.07	.016	5 *b*	5	5371.21	.025	0 *N*
3	5330.65	.017	0	4	5372.03	.018	2
4	5331.909	.009	4 *s*	5	5372.61	.012	2 *b*
3	5332.58	.021	0	3	5373.44	.014	1
4	5333.24	.019	0	4	5374.30	.015	2 *b*
6	5333.638	.011	5 *s*	5	5375.28	.017	1
4	5334.65	.031	0 *N*	5	5376.25	.019	1
4	5335.224	.014	1	5	5377.10	.021	1
4	5335.74	.023	1 *N*	3	5378.29	.063	1 *vb N*
4	5336.59	.015	0	5	5380.49	.022	1 *b N*
4	5337.80	.025	2 *b N*	3	5381.98	.033	0 *N*
3	5338.60	.034	0	4	5382.92	.014	0
4	5339.21	.042	0	3	5383.52	020	1
4	5339.90	.017	1 *N*	3	5384.55	.022	2 *b*
4	5340.82	.049	0 *N*	2	5385.74	.011	0
4	5341.49	.056	0 *N*	2	5386.83	.030	0
4	5342.27	.018	2 *b d N*	3	5387.48	.016	1 *b*
5	5343.18	.015	1	2	5387.93	.028	1 *N*
2	5343.68	.040	0 *N*	2	5388.71	.008	0 *N*
2	5344.42	.063	0 *N*	3	5389.19	.051	0 *N*
4	5344.88	.022	0 *N*	2	5389.85	.008	0
4	5346.02	.021	2	3	5390.36	.028	1

TABLE I — *Continued.*

n	Wave-length	Mean error	Intensity and character	*n*	Wave-length	Mean error	Intensity and character
2	5391.22	0.044	0 *N*	1	5423.15		0 *b N*
3	5392.13	.022	1 *b N*	1	5425.12		0
2	5393.88	.063	0 *vb N*	1	5425.87		0 *N*
3	5395.39	.042	1 *b N*	1	5426.71		0 *N*
3	5396.74	.011	1	1	5427.34		1
2	5398.03	.100	1 *b N*	1	5428.10		1
3	5399.50	.012	0 *b*	1	5429.79		1
2	5401.09	.032	0	1	5432.27		0
2	5402.37	.026	0 *N*	1	5433.95		0
2	5403.62	.023	0 *b N*	1	5434.44		1
2	5405.09	.011	0 *b N*	2	5435.46	.013	1 *b*
2	5405.69	.001	1	2	5436.98	.004	1 *b*
2	5406.73	.020	1	2	5438.21	.018	1 *b*
2	5407.36	.015	1 *N*	2	5438.86	.015	0
2	5408.39	.057	0	2	5439.56	.011	0 *b*
2	5409.02	.006	1	2	5440.77	.005	0 *b*
2	5409.74	.023	0	2	5442.09	.064	0
2	5410.22	.026	0	2	5442.77	.005	1
2	5410.85	.035	0	2	5443.46	.010	0
2	5412.04	.042	1 *N*	2	5444.14	.007	0
2	5412.75	.047	1 *N*	1	5444.67		0
2	5414.65	.053	0 *N*	1	5445.40		0
2	5416.41	.100	0 *b* band	2	5448.42	.005	0
1	5418.37		0 band	2	5449.26	.018	0
1	5420.31		0 band	2	5450.05	.002	0

The line spectrum.—The lines of the absorption spectrum of one meter of chlorine at atmospheric pressure begin at about $\lambda 4799$ and extend to $\lambda 5350$; the first lines in the blue are very faint, as are also, in general, those in the yellow above $\lambda 5200$. Those of maximum intensity lie nearer to the blue end than to the yellow. Few of the lines are sharp, the greater number have ill-defined edges, and not many are very broad. There are numerous pairs of lines, and some groups of three lines; but there is no apparent law in the distribution of these groupings.

The spectrum, especially in the first order, presents to the eye a fluted appearance, or recurring maxima and minima of absorption, which becomes more distinct as the quantity of chlorine is increased. The flutings are narrow at the point where the lines begin in the blue and become gradually broader on going towards the red. Examined under the microscope they do not appear to have heads like those of the carbon bands, nor have they any visibly regular grouping; but the lines in the part of the band which gives the impression of greatest absorption to the eye are somewhat closer together than those in the rest of the band. The lines have all about the same width and intensity. It is possible that this fluted appearance may be due in great part to narrow patches of general absorption superposed on the line spectrum.

The general absorption spectrum.—The general absorption spectrum of chlorine consists of a broad band in the violet which was early discovered and which has been studied by Liveing and Dewar. There are also, perhaps, some smaller patches of absorption superposed on the region containing the line spectrum and giving to it a fluted appearance, as described above. The width of the violet band varies with the pressure and length of the column of chlorine used, and some measurements of it will be given later.

The effect of pressure on the general absorption spectrum.— It is generally considered that the absorption band spectrum of a gas arises from the line of spectrum as the result of increasing the density of the gas in question. Hasselberg,[1] describing the spectrum of nitrogen peroxide, says, that with increase of density new lines appear, not previously visible, and that the old ones become stronger, until together they form broad bands; finally, through increase in the number, blackness and width of the lines, the absorption becomes total. In the case of iodine, he says that with increase of density or of length of column, all the lines increase in intensity and width, and that at the same time a continuous absorption is developed, beginning at the violet end of each fluting and extending towards the red; and that finally the absorption becomes total. Konen[2] describes the same effect on the spectrum of iodine. In emission spectra it is generally considered that a line spectrum may be changed into a continuous spectrum by sufficiently increasing the pressure. It might, therefore, be thought possible to change from a continuous absorption spectrum to a line spectrum by decreasing the pressure. This might take place in two ways: either the continuous absorption would break up into a number of lines scattered over, approximately, the same region that the general absorption occupied, thus being the reverse of what happens in the visible spectrum of iodine and nitrogen peroxide when the density is increased; or, the edges of the general absorption might recede until only one narrow absorption band or line would be left.

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[1] *Mém. de l'Acad. de St. Petersb.* [7], **26**, No. 4, 17, 1878; **36**, No. 17, 8, 1889.

[2] *Wied. Ann.*, **65**, 285, 1898.

Some experiments were made to find what effect the decrease of pressure would have on the general absorption band in the spectrum of chlorine.

The tube 1.37m long being exhausted, chlorine was let in until the total pressure, as measured by a manometer attached, was 30 cm of mercury in one case, and 10 cm and 5 cm in other cases. Further, the steel tube 33.2 cm long was exhausted and filled with chlorine at 10 cm pressure. Photographs were made of the absorption spectrum in each case. In the ultra-violet part the tube 80 cm long fitted with quartz ends was used with the gas at pressures of an atmosphere, half an atmosphere, and about 8 cm. In no case was any trace of a breaking up into lines found. The experiments were not entirely conclusive in this respect in the region of the ultra-violet below the absorption band, for the arc spectrum in this part is not sufficiently continuous to make the decision final as to the non-existence of absorption lines, and the difficulties of photographing became too great beyond λ2500, owing to the increase of the diffuse light reflected from the grating. With the chlorine at atmospheric pressure the general absorption extends to λ4700; at 5 cm it has receded to λ3800. In the region λ4700–λ3800 careful search could, therefore, be made for lines; but none were found. The total effect of a decrease of the pressure of chlorine was a diminishing of the width of the absorption band; hence we may consider the general absorption as a broadened line. If we could sufficiently decrease the pressure we might expect to find this line. It broadens much more rapidly on the less refrangible than on the more refrangible side with increase of pressure, and finally extends into the region of the absorption lines. The same effect on the width of the absorption band may be obtained by decreasing the length of the column of chlorine, and leaving the pressure unchanged as by decreasing the pressure with a given length of column.

The edges of the band are not sharply defined. So that determinations of its width can have only relative accuracy. The following are some measurements for different pressures of chlorine, which are reduced to the equivalent columns at atmospheric pressure.

TABLE II.

Equivalent length of column at atmospheric pressure	Width of absorption band
272 cm.	λ4990 to ....
103	λ4700 " ....
60	λ4650 " λ2599
40	λ4420 " λ2630
14	λ4115 " λ2750
7	λ3850 " λ2881
3.5	λ3718 " ....

The effect of pressure on the line spectrum.—Photographs were taken of the visible line spectrum with the 1.37 m tube filled at 30 cm and 10 cm pressure. In the first case the lines in the blue and green-blue appeared unchanged in position and perhaps a little sharper than when chlorine at atmospheric pressure was used, but the lines in the green-yellow were too faint to be measured. In the second case, with 10 cm pressure, all the lines had become faint.

In order to study the effect of increasing the pressure, a new steel tube 1.36 m long was made, fitted with caps the openings in which were 4.9 cm in diameter. The end glass plates were very carefully ground to the ends of the tube; but notwithstanding the care taken, great difficulty was experienced in using the tube. It held sufficiently well, however, for pressures up to 2½ atmospheres, that is, when the partial pressure of the chlorine was about 2 atmospheres, and it was used at this pressure. The spectrum so obtained showed no new lines in the part where they had been measurable before, but the old ones were much more intense. The broadening of the lines was slight and not nearly so noticeable as their marked increase in intensity. Farther up in the yellow new lines became visible; at the same time the general absorption advanced up to λ4990, so that those lines which had been previously the strongest and sharpest were no longer visible. This spreading out of the general absorption did not appear to come from broadening of the lines, for as far as lines could be seen, which was right down to the edge of the general absorption, they remained hardly less sharp and distinct than before. This absorption, then, is rather to be considered the extension of the general absorption band from the violet up into the green, and the lines become invisible because of the greater intensity of the general absorption.

It seems as if we must consider that there are two absorption spectra here, each of which is separate and distinct from the other. The one is a line absorption, which persists always, though in certain cases it may be invisible, because it is too faint, or, on the other hand, because it is covered over by the general absorption. The other is a general absorption which consists of a broad band in the violet end of the spectrum, and possibly also of little patches, which lend, partly, the appearance of channelings to the line spectrum. With increase of density the lines become stronger, and are unchanged in position; but the general absorption broadens out very much, especially towards the less refrangible end, until it engulfs the lines and renders them no longer visible. The presence of two spectra might be explained by the different action which different groupings of the constituents of the gas may have on light radiations. One could think of the general absorption as due to molecule-complexes, and of the line absorption as due to simpler combinations of the separate atoms. An analogy in emission spectra is the spectrum of the arc light, in which brilliant lines are seen on a continuous bright background, like the superposition of a line spectrum on a continuous one. In the case with which we are dealing it is not to be expected that we could see the absorption lines on the black background with the light used.

As the question of the fixed position of the lines under changes of pressure is of interest, measurements are given in Table I on the lines from λ5165 to λ5218 for chlorine at atmospheric pressure and at two and a half atmospheres pressure. A comparison shows that, except for some lines broadened on the red side, the displacement is, in general, smaller than the error of measurement, and is sometimes toward the blue end and sometimes toward the red. The conclusion is that the apparent differences are due to errors of measurement and differences in setting. It is generally accepted that within moderate limits an increase of temperature has the same effect on the absorption spectra of gases as an increase in pressure. The present experiments have all been made at room temperatures.

COMPARISON OF CHLORINE SPECTRA.

Morren's description of the general appearance of the chlorine absorption spectrum agrees with the results of the present experiments. The region over which lines have been observed has been extended, although the quantity of chlorine has been smaller than that used by Morren. This may be explained by the fact that his observations were made directly with the eye. The truth of the remarks of Gernez concerning the chlorine spectrum is not borne out by the results now found, since, according to the present investigation, 4.68 meters of chlorine (the amount used by Gernez) would absorb a large part of the visible spectrum, and would not give a spectrum extending into the "violet," as his statement reads. There are no measurements given in either case with which to compare the present ones.

The general absorption of 15 mm of liquid chlorine, as given by Gänge, corresponds roughly to that of a meter of chlorine gas at two and a half atmospheres pressure, as the numbers given above for the beginning of the total absorption show.

The results of the experiments here made on the total absorption band in the violet agree with those obtained by Liveing and Dewar. Strict comparison of the measurements on the width of the band is impossible, as Liveing and Dewar do not give details concerning the amounts of chlorine used.

It was not to be expected that the chlorine absorption spectrum would agree with its known emission spectrum. The phenomenon of reversed lines shows that bodies which emit light of certain wave-lengths will also absorb light of those same wave-lengths; and through certain ranges it has been shown that the absorption or emission is independent of the temperature, provided the general mode of vibration remains unaltered. If, however, the mode of vibration changes, owing, perhaps, to some change in the molecular or atomic grouping, the emission at one temperature is not the same as the absorption or emission at another. In the case of iodine, comparison has been made by Konen[1] between the absorption spectrum and the various emission spectra; he states that the absorption spectrum corresponds to the band spectrum of vacuum tubes, to the flame spectrum, and to the glow spectrum obtained by heating the gas in closed vessels.

In the present case the only known chlorine emission spectrum is a line spectrum. The lines lie between λ3276 and λ6758, but the majority are at the violet end, which region is covered in the absorption spectrum of a meter of chlorine by a broad band. In the region which contains lines in both emission and absorption spectra, coincidences were looked for. A large number of lines are nearly coincident, as will be seen from the following table, which contains the wave-lengths and intensities of the emission lines as given by Eder and Valenta,[2] together with the wave-lengths and intensities of the lines lying nearest to them in the absorption spectrum. Except for a few cases the differences are too great to be due to errors in measurement and the relative intensities are altogether different.

[1] *Loc. cit.*, p. 259. [2] *Loc cit.*, p. 8.

TABLE III.

λ_e	I_e	λ_a	I_a	λ_e	I_e	λ_a	I_a
4810.194	9	4809.949	1	5158.9	½	5159.113	4
4819.628	9	4820.059	2	5162.50	1	5162.37	1
4896.905	5	4896.888	2	5173.4	1	5173.43	2
4904.905	4	4904.767	1	5176.0	½	5176.14	4
4917.870	2	4917.943	7	5189.74	1	5189.86	1
4924.90	1	4924.86	3	5193.6	½	5193.54	2
4927.3	½	4927.213	3	5218.07	3	5217.87	2
4943.1	½	4942.905	4	5221.48	4	5221.72	2
4970.3	1	4970.52	6	5285.8	½	5285.63	0
4995.7	1	4995.914	5	5392.300	4	5392.13	1
5078.361	4	5078.543	4	5423.441	6	5423.15	0
5083.59	1	5083.50	1	5423.703	2		
5089.6	½	5089.53	2	5443.587	5	5443.46	0
5099.36	1	5099.53	1	5444.412	3	5444.14	0
5103.18	4	5102.86	2	5445.12	1	5445.40	0
5113.3	1	5113.08	2				

A comparison of the absorption spectra of iodine and bromine with that of chlorine shows that with decreasing atomic weight, increasing amounts of the gas must be used to render visible and distinct the absorption lines. Hasselberg obtained the absorption spectrum of iodine using a column of 10 cm of the vapor, and that of bromine by using a 75 cm column, whereas 137 cm of chlorine was not more than sufficient for the purpose. The given iodine spectrum extends a little farther on the red side than the bromine spectrum, and much farther than that of chlorine even for a 136 cm column at two atmospheres pressure; that is, the lines of this group shift towards the red with increasing atomic weight. This is analogous to the behavior of the emission spectra of any one group of elements, as shown by Kayser and Runge. Hasselberg measured about 3000 lines in the iodine spectrum, and about 2500 in the bromine spectrum; in the spectrum of chlorine only about 1000 have been observed. This number would probably have been increased if still greater amounts of chlorine had been used.

The lines of the iodine spectrum are, according to Hasselberg, fully as sharp and distinct as the solar lines; those of bromine, it is to be inferred, are not so good; and certainly the chlorine lines are much less sharp and well defined than those of the solar spectrum.

As previously mentioned, the earlier investigators observed a similarity in the appearance of the iodine and bromine spectra, but under the dispersion now used, the lines which they observed are seen to be bands composed of a number of lines. These bands appear as channelings in the spectra and continue to make the two spectra appear somewhat similar. These, as already noted, are not absent from the chlorine spectrum, but again iodine has them most distinctly, and bromine and chlorine in diminishing distinctness. If one used the proper densities in all three cases the three spectra could doubtless be made to assume a very similar appearance.

SUMMARY OF RESULTS.

The complete absorption spectrum of chlorine at ordinary temperatures consists of a very broad total absorption band in the violet region, of a line absorption in the blue, green and yellow, and of transparency in the visible red.

The lines do not coincide with the known line emission spectrum of chlorine.

With increase of pressure the absorption band in the violet broadens out rapidly on the less refrangible side, more slowly on the more refrangible side. Decrease of pressure does not break it up into lines.

The total absorption band behaves as if it were a separate absorption spectrum from the line spectrum.

Increase of pressure increases the intensity of the line spectrum greatly and causes new lines towards the red to become visible.

The absorption lines of the elements of the halogen group shift toward the red with increasing atomic weight.

The number and sharpness of the absorption lines of the elements of the halogen group increase with increasing atomic weight.

The amount of gas necessary to render visible the absorption lines of the elements of the halogen group decreases with increasing atomic weight.

In conclusion, it is a pleasure to me to express my deep gratitude to Professor A. Stanley MacKenzie under whose direction this investigation has been carried out, for the constant encouragement and assistance which he has given me during the course of this work.

PHYSICAL LABORATORY,
BRYN MAWR COLLEGE,
June 1901.

SOME PROPERTIES OF THE ELECTRIC SPARK AND ITS SPECTRUM.

By CHARLES C. SCHENCK.

I.

IT is well known that in many spectra the lines are not arranged in haphazard order, and many attempts have been made to divide lines into different groups according to their characteristic behavior, and to associate together lines in the spectra of closely related elements. Professor Ames[1] was the first to point out the intimate connection between certain lines in the arc spectrum of zinc and cadmium, thus determining the so-called homologous lines, and Kayser and Runge have since succeeded in dividing the chief lines in the arc spectra of many elements into their well-known principal, and first and second subordinates series.

The object of the first, or preliminary, section of this paper is to divide the principal lines in the spark spectrum of cadmium into three groups, each having characteristic properties peculiar to itself.

Kirchhoff[2] showed in 1861, and Thalen[3] in 1866, that the spark spectra of certain elements could be transformed into spectra closely resembling the simple flame spectra by inserting a wet string in the circuit containing the Leyden jar and the spark gap, so as to increase its resistance, or by causing the spark discharge to pass through the coils of an electro-magnet, thereby increasing the self-induction.

Hemsalech[4] has also investigated some of the general effects produced in spark spectra by inserting a self-induction in the discharge circuit from a condenser. He has not investigated the ultra-violet region, however, and has confined his attention to the statement of certain general effects observed. He has also recently proposed[1] a division of the lines of spark spectra into groups, which does not quite agree, however, with the classification proposed in this paper, as it does not include any of the lines of Group C, mentioned below.

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[1] *Phil. Mag.* (5) 30, 1890.

[2] *Abhandlungen der K. Acad. Berlin*, 1861, p. 73.

[3] *Annuaire*, Upsala, 1866.

[4] *Jour. de Phys.*, December 1899.

The division of the lines of the cadmium spark spectrum into three groups followed from a detailed study of the changes produced in the spectrum when the period of the condenser was varied by increasing the self-induction.

APPARATUS.

The spark was produced by a 110-volt alternating current, frequency 133 complete periods per second, which was stepped up to about 600 volts and put through the primary of a large induction coil, the potential of whose secondary was raised sufficiently to give a spark one centimeter long. The capacity consisted of six gallon jars connected in parallel, with a total measured capacity of 0.016 microfarads. The 110-volt current was regulated by a suitable resistance so as to give the best spark conditions for the given capacity, *i. e.*, a very noisy spark which should not heat the terminals to incandescence. If the current was too large the poles became very hot, the spark was less noisy, and, as was found later, the spectrum was not the same as with a noisy spark. The best spark was obtained when the 110-volt current was about twelve amperes, and the 600-volt current which passed through the primary of the induction coil was then about one ampere. The spark length varied from 6 to 8 millimeters. With the first-named length, the sparks followed one another with considerable regularity at the rate of 266 per second, and produced a fairly good musical tone, whose pitch was nearly that of middle C. When the terminals were pulled farther apart the regularity ceased, but again appeared at a spark length of about 8 millimeters, when the tone was an octave lower than the first.

The period of the condenser, when the wires connecting it to the spark gap were as short as possible, was found later by photographing the image of the spark by means of a revolving mirror and measuring the separation of the oscillations on the photographic plate. Its value was 1.3×10^{-6} seconds. It should be added that each spark consisted of about ten or twelve complete oscillations.

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[1] *Comptes Rendus*, April 22, 1901, p. 959.

The spectrum was photographed with the large concave grating of 21 feet radius. Some photographs were also taken by means of a small concave grating of 6 feet radius. Some plates of zinc and magnesium were taken for purposes of comparison.

RESULTS.

An examination of the cadmium plates showed the existence of about 143 lines in the ultra-violet, extending from λ 2100 to λ 3700, which have the following characteristic properties:

1. They have a breadth of ⅓ Ångström unit and their edges are hazy. They resemble air-lines somewhat, but they are not air-lines, being absent from the spark spectra of zinc, magnesium, and iron.

2. They extend only about 2 mm out from the poles toward the center of the spark, while the rest of the lines extend clear across the spark gap, with a spark 8 mm long.

3. When the spark length was 5 mm, and the period of the condenser was increased 13 times, *i. e.*, to 17×10^{-6} seconds, by throwing in self-induction, they disappeared from the spectrum, while the other metallic lines were practically unaffected. The period of the condenser was found by the rotating mirror as before, and the number of oscillations for each spark was nearly the same as before, *i. e.*, about 12.

4. They are absent from the arc spectrum, as given by Kayser and Runge and as photographed in this laboratory.

5. None of them are reversed.

These lines constitute the first group (C). Thirty-eight of them situated toward the red end are more hazy than the others, some of them being more than twice as broad, although in all other respects they are similar. Hence I have put them into a sub-group by themselves.

It is interesting to note here that the spark spectrum of zinc has a similar group of lines, while that of magnesium has not.

The second group of lines, (B), includes most of the remainder of the lines known as "spark lines," that is, lines either absent from or else very weak in the spectrum of the arc in air, but prominent in the spark. They have the following characteristics:

1. None of them are reversed.
2. When the period of the condenser was increased about 58 times, *i. e.*, to 75×10^{-6} seconds, some of them disappear and the others shorten up close to the poles, while the rest of the metallic lines extend uniformly across the spark gap. A few of the lines of Group B do extend clear across the spark gap, but they are strong close to the poles only and very weak throughout the center of the spark.

Under these conditions the number of oscillations of the condenser was 16 or 18, somewhat greater than before. The period was obtained in two ways: by photographing the spark with the rotating mirror, and by measuring approximately the self-induction of the coil, *i. e.*, 0.0093 henries and using the formula $T = 2\pi\sqrt{LC}$. The two values agreed to within 3 per cent.

The lines of the third group, (A), are the so-called arc lines. They include most of the lines common to both spark and arc. Some of them, as λ 4413, are extremely weak or absent altogether in the spark and strong in the arc. They form thus a spectrum simpler than that of the arc, and the effect of a self-induction is to make the spectrum of this group more complicated, and approach that of the arc. An examination of my plates showed that the scale of relative intensities among these lines is much closer to that of the same lines in the arc, when the period of the condenser is 75×10^{-6} than when it is 1.3×10^{-6}. In fact, with the period 75×10^{-6}, judging from the relative intensities of the lines, it might be said, figuratively, that I had gotten about "half-way" from the spark to the arc.

These lines possess the characteristic that they extend clear across the spark gap when the period of the condenser is great enough (75×10^{-6}) to cause the lines of Group B to shorten up close to the poles. There is scarcely any doubt that they are due to luminous metallic vapors which fill up the entire spark gap, while the lines of Group B are due to a different phenomenon which will be brought out in the second part of this paper.

Now, since this spectrum (Group A) becomes more complicated, especially in the ultra-violet, as we pass from the spark spectrum toward the arc spectrum by increasing the period of the condenser, it seems probable that the temperature of the metallic vapors in the arc is higher than the average temperature of the vapors in the spark, and that one effect of self-induction is to raise the average temperature of the metallic vapors in the spark. By average temperature I mean a time average, taken throughout the interval during which the metallic vapors remain luminous in the spark. There are other reasons for this conjecture. When the duration of the entire discharge is increased 50 to 60 times, there is more time for the vapors to become heated. Again, it is well known that rapidly oscillating currents produce less heating effect than slowly oscillating ones. Moreover, the poles are intensely hot in the arc and comparatively cool in the spark.

But it is apparent that the effect of self-induction is clearly a double action, a repressive effect upon the lines of Groups C and B, and an enhancing effect upon those of Group A. Its whole effect cannot be explained by saying merely that there is a gradual fall in temperature in passing from the spark to the arc; for the spark is a complicated mechanism, and its temperature varies from point to point, and is also a rapidly varying function of the time.

The following table gives a list of the lines belonging to the three groups in the region from λ 2100 to λ 5379 Å. U. No attempt was made to measure them accurately, no more so than was necessary simply to indicate them. Most of the lines occur in Eder and Valenta's table of the cadmium spark spectrum, and these observers have a few lines toward the red end which I do not find, owing possibly to the fact that in this region they photographed the spectrum of the spark in an atmosphere of hydrogen. Some lines have been omitted, a few of which do not fit in well with any of these groups, while the others are so faint that it was impossible to tell much about them. A list of them is given below.

The following abbreviations are used in the tables:

h —hazy.
vh—very hazy.
s —sharp.
b —broad.
r —reversed.
10—very strong.
1 —very weak.
½ —barely visible.
hR—hazy on red side.
hV—hazy on violet side.
bR—broadened toward the red.
bV—broadened toward the violet.
2b —two Ångström units broad.

Lines marked with an asterisk * are given by Eder and Valenta. Pairs of lines marked]* are given by Eder and Valenta as single lines.

GROUP C.

Intensity	Wave-length	Intensity	Wave-length	Intensity	Wave-length
2	2111.7 *	5	3017.4 *	1	3153.4]
Fairly *s* 3	2224.5 *	3	25.4 *	2	54.2]*
vh 1	2350.4 *	1	27.3	5	57.3 *
2	2426.5 *	1	30.4	3	60.9]
2	2499.9 *	3	35.9 *	6	61.9]*
2	2618.9 *	2	44.2	4	73.6]
s 2	2668.2 *	6	49 0 *	4	74.5]*
Fairly *s* 3	2706.9 *	6	53.3 *	3	76.9 *
2	26.9 *	6	59.5 *	3	78.6 *
s 2	67.0 *	7	65.2 *	2	83.0 *
s 3	2805.5 *	4	69.0]	6	85.6 *
1	2808.8	3	69.4]*	2	95.9]
5	2910.9 *	2	74.0	2	96.5]*
2	26.9 *	4	77.3 *	3	97.9 *
5	48.4 *	7	85.2 *	2	3201.8 *
3	52.1 *	3	88.6]	5	10.2 *
1	53.2	3	89.3]*	2	12.7 *
1	54.6	1	91.0	2	13.8 *
2	64.5 *	3	92.5 *	1	15.5 *
1	65.2	5	95.7]	5	17.8 *
1	70.1	4	96.1]*	3	21.6 *
4	71.4 *	4	3113.2 *	2	24.3
4	87.4 *	5	19.1 *	3	36.7 *
4	96.2]	5	22.0 *	4	64.5 *
3	96.6]*	5	24.7 *	3	77.0 *
1	3003.2	1	28.0	4	83.9 *
2	04.0 *	6	29.5 *	3	86.0 *
3	09.0 *	2	41.7 *	2	3389.8
1	11.3]	1	45.1	2	3423.5
1	11.8]*	2	47.0	2	3486.0
3	14.4 *	1	49.0	1	3695.4

GROUP C.—*Continued.*

SUB-GROUP.

Intensity	Wave-length	Intensity	Wave-length	Intensity	Wave-length
2b, hR 3	3809. *	5	3977.8 *	2	4131.0 *
3	27.	0.8*b* 2	84.8 *	3	39. *
4	37.9 *	1*b* 4	88.3 *	3	42.0 *
3	40.6 *	1*b* 3	91.8 *	1*b* 4	58.1 *
0.8*b* 3	52.4 *	1	4009. *	2	63.8 *
1.2*b* 3	65.4 *	1*b* 2	18.5 *	1	71.6 *
1	89.9 *	2*b* 4	29.2 *	1*b* 2	92.0 *
1*b* 2	99.4 *	1*b* 1	49.4 *	0.7*b* 3	4216.9 *
1*b* 2	3935.7 *	1	54. *	1*b* 3	45.7 *
1.3*b* 6	40.5 *	0.9*b* 5	94.9 *	3	71.2 *
2	50.9 *	1*b* 4	4114.6 *	3	72.9 *
1*b* 6	59.0 *	0.7*b* 2	16.8 *	1*b* 1	94.3 *
5	76.8 *	1*b* 3	27.1 *		

GROUP B.

Intensity	Wave-length	Intensity	Wave-length	Intensity	Wave-length
Trifle hazy 2	2168.8 *	4	2418.8 *	9	3250.5 *
6	2194.7 *	5	69.9 *	3*b* 4	3497.5 *
2	2248.9 *	3	87.9 *	7	3535.7 *
b 9	2312.9 *	1	95.5 *	7	4415.9 *
7	1.2 *	*b* 4	2552.2 *	2*b* 10	5338.6 *
2	75.0 *	*vb* 4	2573.1 *	2*b* 10	5379.3 *
3	77.0 *	10	2748.6 *		

GROUP A.

Intensity	Wave-length	Intensity	Wave-length	Intensity	Wave-length
r 5	2144.5 *	*bR* 6	2677.7 *	9	3261.2 *
5	2239.9 *	3	2712.6	10	3403.7 *
1	62.4	*bR* 4	34.0 *	10	66.3 *
r 8	65.1 *	*bR* 5	64.0 *	9	67.8 *
4	67.5 *	*bR* 4	75.1 *	3	3500.1
br 7	88.1 *	7	2837.0 *	10	3610.7 *
5	2306.7 *	*bV* 1	62.4 *	8	13.0 *
6	2329.4 *	*bR* 5	68.4 *	4	14.6 *
½	2525.6	7	80.8 ⎤	*s* 2	49.7
vh 1	44.9 *	4	81.3 ⎦ *	*hR* 3	3729.2
½	80.3	*bV* 3	2961.7 *	*hR* 4	4307.0
½	92.1 *	8	80.7 ⎤	1	4413.2 *
h ½	2602.0 *	5	81.5 ⎦ *	*bR* 4	4662.7 *
2	29.1 *	½	3005.5	*hR* 10	4678.4 *
1	32.3	*hR* 6	81.0 *	*hR* 10	4800.1 *
4	39.6 *	*hR* 8	3133.3 *	*hR* 10	5086.1 *
h 2	60.4 *	*hR* 8	3252.7 *	*hR* 2	5154.9
h 1	70.7 *				

LINES OMITTED.

Intensity	Wave-length	Intensity	Wave-length	Intensity	Wave length
1	2004.2	*vh* 1	2411.2 *	½	3156.0
1	2055.5	½	2591.1	1	63.2
½	2148.3	½	93.0	*h* ½	87.5
½	51.6	½	96.0	½	90.5
½	55.5	½	2599.3	½	3219.5
1	88.0 *	½	2780.1 *	½	42.9
½	2345.8	*h* ½	2967.5	½	43.9
½	33.3 *	*h* ½	2968.5	*b* 5	3385.3
½	43.0	½	3032.8	*h* 1	4006.0 *
vh 1	55.2 *	½	41.		

II.

The second part of the investigation is a study of some of the properties of the spark and its spectrum by means of photographs taken with a revolving mirror, and an attempt to trace the connection between lines of different groups and also certain characteristic lines in the spectra of magnesium and zinc, and certain phenomena in the spark itself.

The appearance of the spark when viewed in a rotating mirror turning with sufficient velocity to separate out the oscillations of the condenser is well known. Feddersen studied its appearance in 1862,[1] and Schuster[2] has also photographed it by using, instead of a revolving mirror, a rapidly revolving disk to which was attached a sensitive film upon which the image was focused. Its appearance is shown in Plate III, Fig. 1, which was taken by placing a narrow vertical slit in front of and very close to the spark, and allowing the light to fall upon a rotating mirror with vertical axis and thence through the lens of a camera. Its appearance presents three general features.

1. A brilliant white straight line due to the first discharge, which is sometimes followed by one or two similar weaker straight lines at intervals of half the complete period of the condenser.

2. Curved lines of light which shoot out from the poles toward the center of the spark gap with a velocity constantly diminishing

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[1] *Pogg. Ann.*, 116, 1862.

[2] *Phil. Trans.*, 193, p. 209.

as they move away from the poles. It will be noticed that as the light advances from one pole, the light moving away from the opposite pole is either very weak or absent altogether. In a cadmium spark these lines of light are greenish-yellow and in magnesium they are purple.

3. A rather faint light, generally of a different color from the curved lines of light, which fills up the spark gap and persists for a certain length of time, especially in the center of the spark gap, after the oscillations die out.

If the slit is very narrow, this light is not apt to come out on the photograph, owing to under-exposure, but by widening the slit or removing it altogether it is easy to get it, at the expense, however, of blurring the oscillations.

Schuster, by photographing the spectrum on the rotating disk, has shown that it is the first brilliant discharge to which the air-lines in the spark spectrum are due.

APPARATUS.

In order to get a connection between the different metallic lines and the phenomena in the spark, I arranged an apparatus, a section of which by a horizontal plane is shown in the diagram. *A* is the spark, which is vertical. *S* is a vertical slit very close to it. At a considerable distance away, 231 centimeters, was placed a 60° prism, *P*, of flint glass, with its edge vertical. It was set at an angle of minimum deviation for a wave-length about 4500. At *M* was a rotating mirror with its axis horizontal. The mirror was driven by an air blast and its period measured by a speed wheel attached to the axis of the mirror by a worm gearing. The highest speed obtainable was 65 revolutions per second. The light reflected from the mirror passed through a lens and was focused on the ground glass of a camera, *C*. In this way a horizontal spectrum was obtained whose height, *i. e.*, the length of whose lines, was very small (0.7 mm).

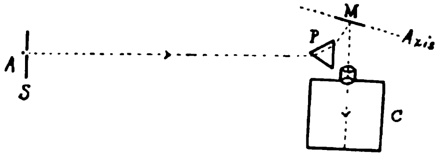

PLATE III.

FIG. 1.

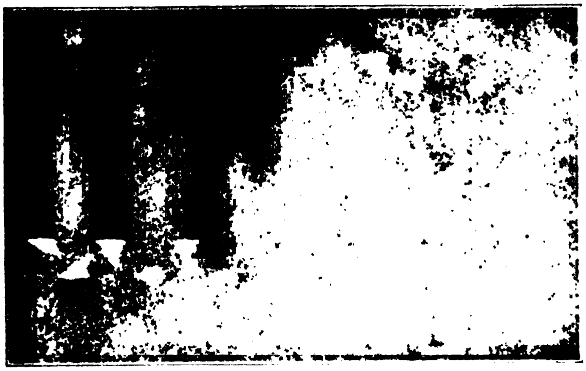

FIG. 2.

By the rotation of the mirror the lines of the spectrum were pulled out in the direction of their length, by an amount depending upon their duration and upon the speed of the mirror. The time of exposure was found by trial, and was taken so that four or five flashes of the spectrum were thrown upon the plate, as a rule in different places. Photographs were taken using pairs of cadmium, zinc, and magnesium electrodes, and also by using one electrode of cadmium and one of magnesium, etc. By measuring the length d, of any line on the plate as pulled out by the mirror, and knowing the period of the mirror, T, the optical distance from the slit to the mirror, r, the small angle, 2θ, between the incident and reflected light at the surface of the mirror when the normal to its surface lay in a horizontal plane, and the magnification, f, of the image of the slit in the camera, it was easy to calculate the duration, t, of the different lines by the formula,

$$t = \frac{Td}{4\pi f r \cos\theta} .$$

With this apparatus,

$$r = 230.9\,\text{cm}$$
$$f = \tfrac{6}{55}$$
$$\frac{1}{\cos\theta} = 1.043 .$$

The first striking characteristic of the lines was that the principal arc lines (Group A) were at least twice as persistent as the strongest spark lines (Group B).

The following table gives an example of the duration of some of the principal lines of magnesium, zinc, and cadmium.

	Line		Duration
Magnesium	4481	strong spark line	24×10^{-6} seconds
	3838 3832 3830	strong arc triplet	45×10^{-6}
Zinc	4925	strong spark lines	14×10^{-6}
	4912		14×10^{-6}
	4811	strong arc lines	24×10^{-6}
	4722		24×10^{-6}

	Line		Duration
Cadmium	4800 4678	strong arc lines	36×10^{-6}
	4416	strong in spark, extremely weak in arc	18×10^{-6}

It was determined by eye observations that the duration of the principle arc lines was even greater than is indicated in the above table, the extreme end of the lines not appearing on the photograph owing to under-exposure.

The period of the condenser was 1.3×10^{-6} seconds. The duration of the continuous spectrum, which appeared quite strong by using such a small dispersion, was exceedingly short; *i. e.*, less than the period of the condenser. The air lines also, as might have been expected from Schuster's results, persisted for a length of time equal to one or two periods only.

Now, owing to the fact that the height of the spectrum is not small enough, and also that the mirror could not be run faster than 65 revolutions per second, it was impossible to show oscillations in the lines by this arrangement, but by increasing the period of the condenser to 5×10^{-6}, by a small self-induction, and by using poles of unlike metals, say zinc and cadmium, the oscillations were brought out very clearly.

A second characteristic of the lines was that the spark lines (Group B), appeared sharply beaded clear out to their ends, as a result of the oscillations, while the arc lines (Group A) showed only indistinct traces of beading, which did not extend all the way out to the ends of the lines. In other words, the spark lines are due entirely to the oscillations, and the arc lines are due partly to the oscillations and partly to something else which retains its luminosity after the oscillations cease. On some of the photographs the magnesium arc triplet at λ 3830 began a trifle later than the spark line λ 4481. This fact will be referred to later.

This seemed to point to a connection between the spark lines and the curved streams of light seen in the spark itself when viewed in a revolving mirror. To show this clearly, the mirror

PLATE IV.

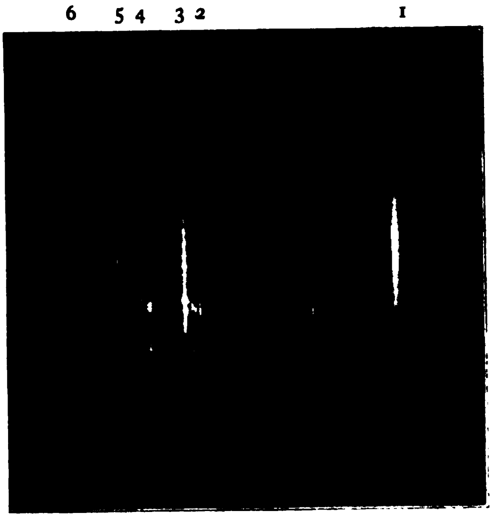

FIG. 3.

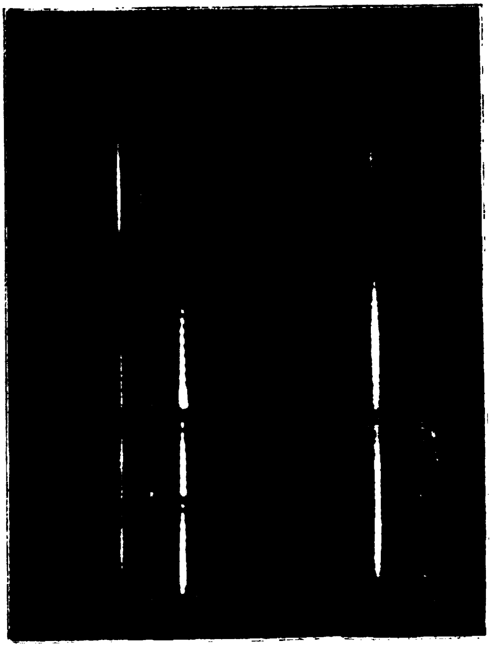

FIG. 4.

was turned over in order that its axis might be vertical, and the front half of the camera lens was removed so as to get a higher spectrum, *i. e.*, one whose lines should be longer, and also to spread out the oscillations. The period of the condenser was again reduced to 1.3×10^{-6}, by removing the self-induction, and magnesium poles were used on account of the extreme brilliancy of the spark line λ 4481. In the photograph, this line appeared broken up into a beautiful series of curved lines similar to the curved streamers in the spark itself.

In order to see if there were an exact similarity between the streamers in the spark and those into which this magnesium line was broken, the apparatus was arranged as follows: An image of the spark was focused on a vertical slit by means of a lens. The light then passed through a collimating lens, was transmitted through the prism in a parallel beam and fell upon the revolving mirror (with vertical axis), from which it was reflected into the camera, and the spectrum brought to a focus on the ground glass. The prism was mounted upon a sliding block, and a plane vertical silvered mirror was placed near its refracting edge upon the same block, so that, by sliding the block, a part only of the light passed through the prism, while the rest struck the silvered mirror from which it was reflected to the revolving mirror and thence into the camera, forming an undispersed image of the slit alongside of the spectral image. By tilting the silvered mirror very slightly out of the vertical, the undispersed image was thrown on the plate slightly above and one or two centimeters to one side of the spectral image. By this means it was possible to get a plain and a dispersed image of the *same* spark which did not overlap when the mirror was spinning. But no difference was found on the photograph, between the appearance of the streamers in the plain spark and those in the line λ 4481, every slight irregularity in the one appearing also in the other.

It was not found possible, on account of lack of light, to photograph the arc lines by any of these methods with the axis of the mirror vertical, without cutting down the speed of the mirror so much as to run the oscillations together. But even under these conditions the arc lines showed certain interesting features. The light from the magnesium triplet λ 3830 advanced from the poles toward the center of the spark gap with substantially the same velocity as that from the line λ 4481, but with feeble intensity, and burst out in the center of the gap with increased brilliancy an instant later, where it remained until some time after the spark line λ 4481 had ceased. This agrees with the fact, mentioned on page 126, that this arc triplet began a trifle later than the spark line λ 4481, its feeble intensity at the start not appearing on the photograph referred to on that page.

But in order to establish the exact connection between the principal arc lines and the curved streamers in the plain spark, it was necessary to resort to eye observations. The following apparatus was set up: The image of the spark was thrown on the slit of a Steinheil spectroscope containing two flint-glass prisms, and the eyepiece of the observing telescope was removed so that the spectrum was brought to a focus in the focal plane of the telescopic objective. A vertical slit was placed at the spectrum so as to transmit the light of any particular line desired. The light then fell upon the rotating mirror (with vertical axis) about 16 inches away, and was reflected into the camera and brought to a second focus on the ground glass. By spreading out the oscillations with a small self induction the following phenomena could be clearly seen by careful observation.

For cadmium.—The strong spark lines λ 5339 and λ 5379 appeared as a beautiful series of curved streamers sharply defined and separated clearly by dark spaces. The last two or three streamers did not proceed very far from the electrodes and the center of the spark gap at this instant was dark.

The line λ 4416 (strong in spark and very weak in arc) also showed oscillations, but its total duration was only about half that of λ 5339 and λ 5379.

The strong arc line λ 5086 also appeared as a series of curved streamers which were *not* clearly separated by dark spaces, and the center of the spark gap remained filled with light after the streamers ceased. Its total duration exceeded that of λ 5339 and λ 5379.

For magnesium.—The strong spark line λ 4481 appeared (as had been previously proved by the photographs) as a series of clearly defined curved streamers.

The strong arc triplet at λλ 5184, 5173, 5168 (*b* lines) also appeared in the form of curved streamers, but there was, besides, a luminosity which persisted long after the streamers ceased, so that the total duration of these lines was about four times that of λ 4481. The luminosity lasted longest in the center of the spark gap.

The oscillatory character of these lines was also verified visually by Mr. L. A. Parsons, Fellow in this University.

RESULTS.

It follows from these observations and the photographs, that the strong spark lines λ 5339 and λ 5379 of cadmium (Group B), and λ 4481 of magnesium are due entirely to the curved streamers in the spark; also that the spectrum of the last few streamers in the cadmium spark does not contain so many lines as that of the first few, *i. e.*, the line λ 4416.

The principal arc lines λλ 5086, 4800, 4678 of cadmium (Group A), and the triplets at λ 5170 and λ 3830 in magnesium are also due partly to the streamers, but a large part of their luminosity is due to something else which appears in the center of the spark gap a trifle later than the first discharge, spreads throughout the gap and retains its luminosity after the streamers cease, retaining it longest in the center of the gap.

This latter luminosity is without doubt due to the metallic vapors.

The fact that the arc lines are due in part to something else besides the streamers was rather strikingly shown by inserting a considerable self induction (0.0093 henries) in the spark circuit. As stated above, the principal spark lines show a tendency to shorten up close to the poles while the arc lines go clear across the spark gap. Now when the spark itself is viewed in a rotating mirror under these conditions, the streamers do not advance so far from the poles as with the ordinary spark, while the center of the spark gap is filled with a pale light whose color and intensity are quite different from those of the streamers.

Fig. 2 is a photograph of the spark under these conditions using cadmium electrodes. The streamers come out on the photograph, but the faint light in the center of the spark, while clearly visible to the eye, was too faint to appear on the negative. The period of the condenser was in this case about fifty-eight times as great as with the ordinary spark. It will be noticed that the initial straight discharge has disappeared. This was to be expected, since Schuster showed that a self induction cuts out the air lines, and that the air lines are due to the initial discharge.

The streamers emanate from the kathode.— It is known already that the streamers proceed from a pole of the same nature. Feddersen's results were somewhat irregular so that he was unable to lay down any general law as to which pole emitted the stronger luminosity. In order to determine whether this were kathode or anode, I charged the condenser by an electric machine and carefully tested the electrification of its terminals with a gold leaf electroscope just before the spark passed. Two or three photographs of the spark were taken under these conditions using magnesium electrodes. Knowing the electrification of the poles at the first discharge, it was comparatively easy to tell from the photographs whether the streamers proceeded from a positively or a negatively electrified electrode. In each photograph they proceeded from the negatively charged pole.

The streamers do not carry the current.— It is easy to see by an inspection of the plates that the streamers shoot out from the poles with gradually diminishing velocity, and that before they get more than half way across the spark gap, the entire charge has passed across and the return oscillation is beginning.

Spark with very hot poles.— It must be remembered that the results of this investigation hold only for comparatively cool electrodes. With magnesium poles, by inserting a small self induction and increasing the primary current from 12 to 25 ampères, small white-hot globules formed on the electrodes. When this occurred, the noise of the spark greatly diminished, the spectrum showed marked changes, and the appearance of the spark in the rotating mirror was quite different. The strong spark line λ4481 shrunk down close to the electrodes, while the arc triplet at λ5170 did not. The spark when viewed in the mirror showed a luminosity advancing from the poles to the center of the spark with far less velocity than that of the customary streamers. As far as could be made out, there were also feeble streamers present which advanced only a short distance out from the poles. Every now and then the little globules would fly off the poles, the loud noise would return, and the ordinary streamers would instantly reappear in the spark. The spark line λ4481 then stretched clear across from pole to pole.

The result of this investigation may be expressed briefly by saying that the chief cause of the complexity of the spark spectrum is the presence of the luminous streamers in the spark.

As to their nature, they may be luminous pulses, something like those that occur in a Geissler tube discharge. Or they may be metallic vapors, the peculiar vibration of whose atoms is set up by the act of tearing them off the electrodes; as they moved off from the electrodes, the abnormal vibrations would die out, while the more fundamental vibrations, principal arc lines, would persist—would indeed be augmented by the passage of the to-and-fro currents through the vapors.

In conclusion, the author wishes to express his thanks to Professor Ames for his kindness and for the many fruitful suggestions made during the course of this work.

ADDENDA.

EFFECT OF A STRONG MAGNETIC FIELD.

Some experiments were also made upon the effect produced by placing the spark in a strong magnetic field. The spark terminals were placed between the poles of a large electro-magnet, and a mirror was arranged so that light from the spark which was propagated along the lines of magnetic force was reflected to a lens, thence to a slit upon which the image of the spark was focused. The light then passed along to a collimating lens, to the revolving mirror with vertical axis, from which it was reflected through the lens of a camera and brought to a focus on the ground glass, the lens being adjusted for parallel rays. By a variation in the above arrangement, the light from the collimating lens could be made to pass through a couple of prisms, then through another lens, then, at a distance away sixteen inches greater than the focal length of the last lens, upon the revolving mirror, and into the camera. By the latter arrangement, the behavior of the separate lines of the spectrum could be studied when subjected to a strong magnetic force.

Perhaps the most interesting feature of the change produced is that the spark lines (Group B) and the arc lines (Group A) behaved quite differently. With no magnetic field they were both long lines, *i. e.*, extended clear across the spark gap. With the magnetic field, the magnesium spark line λ 4481 extended outward from each pole only about a quarter of the way across the gap, leaving the center free from light of this wave-length, while the arc triplet at λ 5200 extended clear across as it did without the field. When examined with the mirror revolving, the line λ 4481 was broken up into a series of short streamers separated by intervals of darkness, while the arc triplet λ 5200 was in the form of a luminosity which advanced slowly (with a velocity not greater than 0.5×10^4 cm per second) toward the center of the spark gap, where it remained luminous for about 160×10^{-6} seconds, the luminosity as it moved from the poles to the center of the gap being crossed by a series of streamers. The noise of the spark was increased by the magnetic field.

In these experiments the period of the condenser was 5.5×10^{-6} seconds, the strength of the field about 10000. The velocity and duration of the luminosity were measured by a series of careful visual observations.

PLATE V.

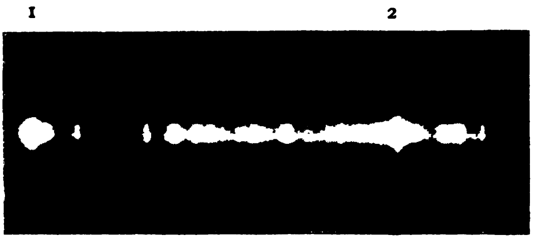

FIG. 5.

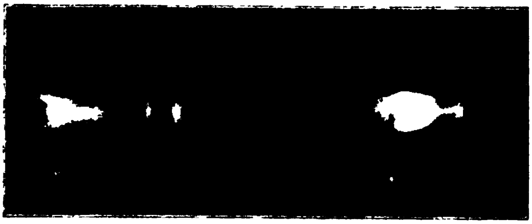

FIG. 6.

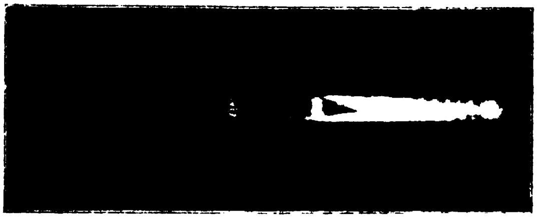

FIG. 7.

Velocity of the streamers.—As there are two distinct phenomena in the spark that might indicate the velocity with which the metallic vapors advance from the poles toward the center of the spark gap, a few plates were measured up in order to distinguish between them,

1. By measuring the slope of the streamers in the magnesium line λ 4481 on a photograph of the spectrum taken with the revolving mirror, it is possible to determine the velocity with which the streamers shoot out from the poles. The value of the velocity obtained in this way was not far from 25×10^4 cms. per second. About a millimeter out from the pole the velocity falls to 16 or 18×10^4.

2. Now the appearance of the line λ 4481 in the rotating mirror often shows a peculiarity which would seem to indicate a second velocity. The first streamer shoots out only a little way, the next one a little farther, and the third still farther, so that the locus of the extremities of successive streamers, when viewed in the rotating mirror, forms an inclined line which is sometimes fairly straight but which is sometimes irregular, owing to the fact that the distances to which successive streamers advance do not increase strictly in arithmetical progression. If the slope of this line be regarded as indicating a velocity it gives a value less than one fifth of the maximum velocity of the streamers, *i. e.*, about 4×10^4. Now, this is not far from some of the values found by Schuster[1] and Hemsalech in their work on the spark, and interpreted by these observers as the velocity of the metallic vapors. But the appearance of my negatives points to the conclusion that the slope of this line does not indicate a velocity, but is in most cases a sort of envelope of successive streamers, and that this is probably what Schuster and Hemsalech have measured in many cases. As pointed out by Schuster, this apparent velocity is not far from that of a sound wave, and if we assume that the violent sound emitted by a spark is produced by the expansion of a column of air raised to high temperature and therefore to high

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[1] *Phil. Trans.*, 193, pp. 189–213.

pressure by the first discharge (for if the temperature of a gas is raised, the density remaining constant, the pressure is raised also), it is rational to suppose that the distances to which successive streamers advance would increase as the pressure of the air which opposes their motion becomes less and less.

JOHNS HOPKINS UNIVERSITY,
Baltimore, Md., June 1901.

DESCRIPTION OF THE PHOTOGRAPHS.

Plate III, Fig. 1. Spark, cadmium electrodes. Period of the condenser, 5×10^{-6}. Mirror is turning in such a direction that light appears at the left of the image first. In this photograph the exposure was so long that another spark happens to have struck the plate just to the left of the principal one. A fragment of a third spark appears above the latter, which was gotten by raising the lens of the camera. There is also a luminosity which persists after the oscillations die out, which fails to appear on the photograph, owing to under-exposure.

Plate III, Fig. 2. Spark, cadmium electrodes. Period of condenser, 75×10^{-6}. Three images appear upon the plate. In the upper two, the plate was not long enough to catch more than two or three oscillations.

Plate IV, Fig. 3. Spark spectrum photographed with rotating mirror whose axis of rotation is horizontal. The lines are thus pulled out vertically upwards. The upper pole is magnesium and the lower, cadmium. One notices the distinct beading in the magnesium spark line λ 4481, (3), and the indistinct beading in the arc triplet λ 3830, (1). The greater duration of the latter is also apparent, though not very clearly so on this particular photograph. The oscillations in the cadmium spark line λ 4415, Fig. 2, also appear, but those in the arc lines $\lambda\lambda$ 4678, (4), 4800, (5), and 5086, (6), do not. This is because the mirror is turning in the most favorable direction for bringing out the oscillations in the magnesium, and not in the cadmium lines. The magnesium line λ 4481, (3), being due to puffs that shoot downwards from the poles, the action of the mirror is to diminish or to arrest their apparent motion, thus separating them into a series of distinct beads. With the cadmium lines the puffs shoot upwards, and the mirror prolongs each into a line of light thus rendering the oscillatory effect less clearly visible. I have another negative taken with the cadmium pole on top in which the oscillations of the cadmium lines are clearly shown, to the detriment, however, of those of the magnesium lines. It will be noticed that two separate sparks appear on this negative, shown by the two sets of air lines. The lower part of the magnesium line λ 4481 belongs to the lower spectrum. With the mirror at rest the length of all the lines would be about the same as that of the upper set of air lines.

PLATE VI.

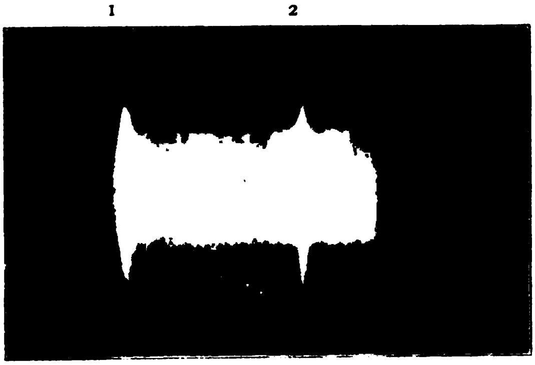

FIG. 8.

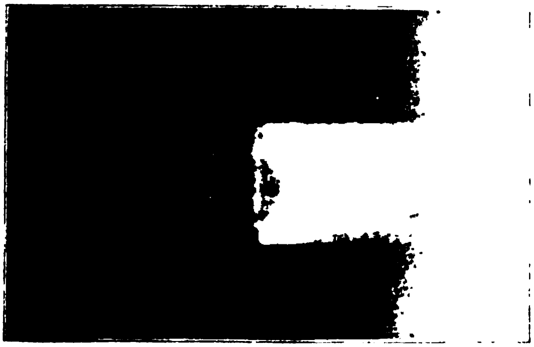

FIG. 9.

Plate IV, Fig. 4. Same as Fig. 3 except that four flashes of the spark appear. The air lines also are somewhat weak on the enlarged print. It will be remembered that these impressions are not made by four *consecutive* sparks, as the interval between consecutive sparks was 100 times as great as the entire duration of a single spark. In Figs. 3 and 4 the period of the condenser was 5×10^{-6}.

Plate V, Figs. 5, 6, and 7 show the magnesium spectrum with the axis of the mirror vertical. In Fig. 5 the mirror is at rest, in Fig. 6 it is making 11¼ revolutions per second, and in Fig. 7, 65½ turns per second. In Fig. 6 we notice the tendency of the arc triplet at λ 3830, (1), to appear most brilliant in the center of the spark gap; also its greater persistence compared with the spark line λ 4481, (2). In Fig. 7 the spark line 4481, (2), appears broken up into a regular series of twelve or more streamers. We also see the two *less* steeply inclined lines of light advancing from the poles to the center of the spark gap, where the line λ 4481 starts out. The arc triplet at λ 3830, (1), does not appear, owing to lack of light, while the air lines are scarcely changed by the rotation of the mirror.

Plate VI, Figs. 8 and 9 show also the separation of the same line, λ 4481 magnesium, (2), into a succession of about eighteen curved streamers, the air lines being straight and hazy. The arc triplet at λ 3830, (1), again disappears for lack of light. The horizontal lines of light in Fig. 9 are due to inequalities in the width of the slit. The spark length was the same, seven millimeters, in Figs. 5, 6, 7, and in Figs. 8 and 9, but Figs. 5, 6, and 7 were taken with the objective prism, and Figs. 8 and 9 with a collimating lens which produced a wider spectrum. In Figs. 5, 6, 7, 8, and 9 the period of the condenser was 1.3×10^{-6}.

MINOR CONTRIBUTIONS AND NOTES

NOTE ON A NEW FORM OF RADIOMETER.

THE radiometer, as described by E. F. Nichols (*Wiedemann's Annalen*, 60, 401, 1897), was found by the writer to possess a few disadvantages in point of ease of adjustment, to overcome which a different form of case was devised. The difficulties found were as follows: (1) air was very apt to leak into the apparatus; (2) the suspended system frequently became charged with static electricity and thereby took on a short period; (3) it was inconvenient not to be able to turn the suspension about a vertical axis, if from any cause, such as electrification, it became necessary to do so to keep the vanes in the desired direction.

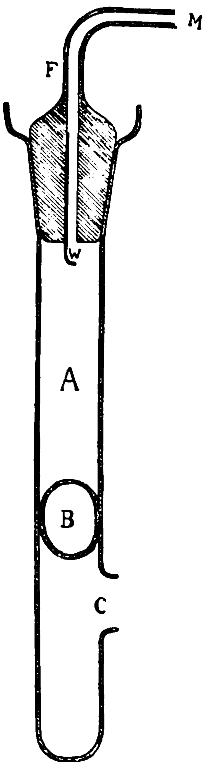

FIG. 1.

The form of case finally adopted was as shown in Fig. 1. The tube *A* was of heavy glass 1.5 cm inside diameter, and near the lower end of it were blown two openings, facing, as usual, in directions at right angles to each other, the outside edges of which were ground flat, so that they could be closed with plates. The two openings were sufficiently far apart so that stray radiation from the beam used to illuminate the moving mirror could not reach the sensitive vanes, and the whole inside of the tube was deeply blackened, a little of the blacking being scratched off in one or two places, where necessary, to allow the system to be seen and adjusted in position. The lower opening, *C*, was closed with a small spectacle lens of one meter focal length, sealed in with wax, and the motions of the mirror of the system were observed by means of a beam focused by this lens. The opening *B* was closed as shown in Fig. 2, which is a vertical section through *B*. *P* was a brass plate cemented to the glass, with a hole in the middle of it of suitable size to admit the beam of radiation to be studied and to be covered by a small plate of polished rock salt *S*, which was cemented to it. *T* was a small piece of tin, fastened to the glass inside, supporting a second plate of rock salt *R*, which stood opposite the sensitive vanes at the distance required for great sensitiveness. This distance could be varied at will by altering the level of the apparatus. A couple of small strips of tin foil, pointed and cut at the ends passed from *P* along *T* and projected into the tube and over part of *R;* these served to dissipate the static electric charges which arose when the air was drawn out of the tube or when the wax used as a cement was touched.

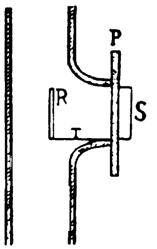

FIG. 2.

The upper end of the tube *A* was ground for a mercury-sealed joint into which fitted another tube *F*, including a mercury-sealed stopcock at *M* and leading to the air pump. A wire *W* was attached to the lower part of the tube *F* and a very fine quartz fiber hung from this inside the tube *A* and supported the radiometer system. The whole radiometer was supported by a sort of Julius suspension. When.the radiometer is attached to the pump, this arrangement is slightly disturbed, but only slightly, as there must be one or two rubber joints between the radiometer and the pump, which assist in preventing the passage of mechanical disturbances along the tubes. The joints about the openings *B* and *C* may, however, on account of their smallness and simplicity, be so perfectly sealed as to admit of the pump being completely detached for a month at a time. A leak at the upper end of the tube is impossible if the mercury seals are in order. The radiometer may then be left free and the Julius suspension may be used with complete success.

In this condition the radiometer is nearly free from mechanical disturbances, the system may be turned at will without changing the pressure within the tube, and thus the zero point may be adjusted ; the electric charges are dissipated within an hour or two after exhaustion, and the apparatus is practically air-tight. Its high sensitiveness and, in this form particularly, its cheapness and ease of adjustment, make it an extremely valuable instrument for radiation experiments.

F. A. SAUNDERS.

SYRACUSE, N. Y.

SOME RECENT RESULTS SECURED WITH THE MILLS SPECTROGRAPH.[1]

The results contained in this *Bulletin* are a few of those recently established by the Mills spectrograph, used in connection with the 36-inch refracting telescope. The majority of the photographs upon which the results depend were made by Assistant Astronomer W. H. Wright, and the remainder by Dr. Reese and myself.

W. W. CAMPBELL.

June 20, 1901.

I. A LIST OF SIX STARS WHOSE VELOCITIES IN THE LINE OF SIGHT ARE VARIABLE.

The following six spectroscopic binaries, discovered with the Mills spectrograph, are additional to the twenty-five already announced.

π CEPHEI ($\alpha = 23^h\ 05^m$; $\delta = +74^\circ\ 51'$)

The binary character of this star was suspected in August 1899, from the fact that the approximate measures and reductions of the first and third plates showed a range of four kilometers in the observed velocities. Later plates confirmed the fact of the variation. The observations to date are as follows:

	Date		Velocity
1899	August	8	– 33km
	August	23	– 36
	August	29	– 37
1900	October	7	– 5
	December	24	– 23

o_1 31 CYGNI ($\alpha = 20^h\ 10^m$; $\delta = +46^\circ\ 26'$)

The variability was detected in July 1900, from the third plate.

	Date		Velocity
1899	June	20	– 12km
	July	2	– 11
1900	July	30	– 3
	August	12	– 3
	October	7	± 0
1901	June	5	+ 3

This star was discovered to have a composite spectrum by Harvard College Observatory. [*Annals H. C. O.*, **28**, 93.]

ξ PISCIUM ($\alpha = 1^h\ 48^m$; $\delta = +2^\circ\ 42'$)

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[1] *Lick Observatory, University of California, Bulletin* No. 4.

The variable velocity of this star was discovered in September 1900, from measures of the third plate.

	Date	Velocity
1899	September 5	+ 25 km
	September 19	+ 27
1900	September 17	+ 33
	December 26	+ 35

τ PERSEI ($\alpha = 2^{h}\,47^{m}$; $\delta = 52^{\circ}\,22'$)

The variable velocity of τ *Persei* was discovered from the fourth plate of its spectrum, in October 1900.

	Date	Velocity
1898	October 26	+ 10 km
	November 14	+ 8
	November 28	+ 8
1900	October 15	— 2
	October 31	— 3
	December 17	— 4

It was discovered at Harvard College Observatory that this star has a composite spectrum. [*Annals H. C. O.*, 28, 93.]

ξ_1 CETI ($\alpha = 2^{h}\,08^{m}$; $\delta = 8^{\circ}\,23'$)

The variable velocity of this star was discovered from the fourth plate, in October 1900.

	Date	Velocity
1897	October 27	— 9 km
1898	October 10	— 7
	October 17	— 8
1900	October 29	+ 4
	December 4	+ 1

ϵ HYDRAE ($\alpha = 8^{h}\,42^{m}$; $\delta = +\,6^{\circ}\,48'$)

The variable velocity of this star was detected from the third plate, in December 1900.

	Date	Velocity
1899	November 27	+ 43 km
	December 26	+ 43
1900	December 3	+ 35
	December 24	+ 40
1901	April 23	+ 32

II. RADIAL VELOCITIES IN THE SYSTEM OF δ *EQUULEI.*

This is one of the most interesting double stars known, discovered by Otto Struve in 1852. Its period of revolution was supposed to be

11.4 years. It was placed on the observing program for the Mills spectrograph, and its radial velocity was observed, as follows:

Date	Velocity
1900 June 25	– 14 km
July 9	– 13

No peculiarities such as doubling of the lines due to the two components, were apparent in the spectrum. This result was anticipated, as the two components were known to be moving approximately parallel to the line of nodes of their orbit; that is, at right angles to the line of sight.

In September 1900, Assistant Astronomer Aitken's observations of this star showed that the long-accepted orbits were unsatisfactory [*Publ. A. S. P.*, **12**, 255–257]; and Astronomer Hussey's investigations rendered it probable that the period is only 5.7 years [*Publ. A. S. P.* **12**, 215–223].

Special efforts have been made to secure spectrographic observations of δ *Equulei* this spring with a view to solving the difficult question of the star's period. A few successful negatives have been obtained within the past two months. The spectra of the two components are clearly shown with displacements corresponding to a relative velocity at present of about 35 kilometers per second. If the distance between the corresponding lines decreases and vanishes in the next few months, we shall have conclusive proof that the period of the star is in the vicinity of 5.7 years; otherwise the longer period should have the preference.

III. RADIAL VELOCITIES IN THE SYSTEM OF *POLARIS*.

It was discovered in August 1899, from observations made with the Mills spectrograph, that α *Ursae Minoris* (*Polaris*) is a triple star. A few observations secured that month showed at once that the bright component was moving around the center of mass of itself and an invisible companion in a period of about 3 days 23 hours. Six observations secured in 1896, extending over three months, were best satisfied on the assumption that the period is $3^d\ 23^h\ 15^m$. A comparison of the 1896 and 1899 observations furnished a period of $3^d\ 23^h\ 14^m.3$.

The velocity of the center of mass of this system varied from — 18.0 km per second in 1896 to — 11.8 km in 1899, thereby affording proof that this system was revolving around the center of mass of itself and a third body in a relatively long period of time.

Further observations have been secured at intervals since August 1899, for the purpose of detecting the first evidence of change in velocity of the center of mass of the short period system. Changes suspected in the latter half of 1900 have now become certain; the velocity of the center of mass of the binary system has varied from — 11.8 km in 1899 to about — 13.5 km at the present time.

The period of the binary system, $3^{d}\ 23^{h}\ 14^{m}.3$, deduced in 1899 seems to satisfy recent observations perfectly.

IV. THE RADIAL VELOCITY OF α *PERSEI.*

Mr. H. F. Newall, from observations made at Cambridge, England, has announced [*The Observatory*, December 1900] that the velocity of α *Persei* is variable. His results lie between — 4 and + 8 km per second and were secured in the years 1899 and 1900. The following table contains all the Mills spectrograph observations of this star, with the time-intervals between successive dates:

Date			Velocity	Interval
1896	November	11	—2.0 km	
				1 day
	November	12	—1.8	
				68
1897	January	19	—3.5	
				539
1898	July	12	—2.1	
				440
1899	September	25	—1.5	
				447
1900	December	16	—2	
				10
	December	26	—2	
				4
	December	30	—2	
				0
	December	30	—3	
				14
1901	January	13	—2	

These ten observations, made in six different years, exhibit a range of only two kilometers. Since this is about the usual range for such stars, due largely to changes in the observer's personal habits in measuring the plates, we may say that these observations afford no evidence of variable velocity.

V. THE RADIAL VELOCITY OF θ *URSAE MAJORIS*

Observations of this star at Pulkowa in the years 1894 and 1896 by Dr. Bélopolsky gave results ranging from + 1 km to + 22 km per second;

and it was announced as a spectroscopic binary with a period of from five to seven days. [*Astr. Nach.*, No. 3549; ASTROPHYSICAL JOURNAL, **11**, 383]. Results obtained by the same observer in February and March 1899, ranging from + 7 km to + 19 km, were considered by him to furnish no evidence of variable velocity during those months [*Astr. Nach.*, No. 3603].

The Mills spectrograph observations, as published below, do not indicate variable velocity:

	Date	Velocity
1897	November 16	+ 15 ± km
1899	December 18	+ 16
	December 24	+ 15
	December 27	+ 14
1900	January 30	+ 14
1901	January 27	+ 14

VI. THE VARIABLE VELOCITY OF δ *ORIONIS* IN THE LINE OF SIGHT.

The variable velocity of this star was discovered by M. H. Deslandres from observations made with the great Meudon refractor. This star is not on the program for the Mills spectrograph, as its lines are very broad and unsuitable for accurate measurement. However, Mr. Wright has secured three observations, as below, which confirm M. Deslandres' discovery:

	Date	Velocity
1900	August 12	+ 3 km
	August 21	+ 51
	September 17	— 69

VII. THE VELOCITY OF *GROOMBRIDGE* 1830 IN THE LINE OF SIGHT.

The star No. 1830 in Groombridge's catalogue is of special interest on account of its large proper motion. Its position in the heavens is changing at the rate of 7″.05 per year, a speed sufficient to carry it over one degree in five hundred years. This was the maximum stellar motion known up to the year 1898, at which date an eighth-magnitude star in the southern hemisphere was found to have a proper motion of 8″.7 per annum.

Several determinations of the parallax of *Groombridge* 1830 have been made. The separate results differ widely in value, but they are in substantial agreement in placing the star at a great distance. From a consideration of the merits of the individual determinations, Newcomb has adopted 0″.14 as its most probable parallax. Assuming this to be its true value, the component of the star's velocity at right angles to the line of sight is 240 kilometers (150 miles) per second. This is by far the largest cross-motion assigned for any of the stars whose parallaxes have been measured.

Inasmuch as the proper motion, both in arc and in linear measure, takes account of the component measure at right angles to the line of sight, it is of unusual interest to have a determination of the component of speed in the line of sight. This determination has been made with the Mills spectrograph, after replacing its three dense prisms by one light prism.

Four spectrum photographs have recently been secured, of which two are very satisfactory, and one is excellent. The results given by the four are in substantial agreement; those given by the best two are — 93 and — 97 kilometers (58 and 60 miles approach) per second, for the dates 1901 March 18 and April 1, respectively. Their mean value, — 95 kilometers, is possibly uncertain to the extent of 5 kilometers.

In view of the great uncertainty existing in the value of the parallax, no interest attaches to the resulting value of the angle for the direction of the star's motion in space.

Groombridge 1830 is of the 6.5 visual magnitude. The photographic magnitude, on the *Draper Catalogue* standard, must be in the vicinity of 7.5. The spectrum is approximately of the solar type, though it may incline strongly toward the characteristics of *Procyon* or *α Persei.*

The best photograph was secured with an exposure of two hours, in average seeing, using slit-width 0.032 mm. As the collimator is 28.5 inches long, and the camera 16 inches, the equivalent of slit-width, so far as purity is concerned, for a collimator equal in length to the camera, would be 0.019 mm. The measurable lines on this plate are between λλ 4000—4415. The region λ 4415—*Hβ* is overexposed. The spectrum is about 0.25 mm in width. The light flint prism used gives approximately two ninths as much dispersion as the three Mills prisms.

The greatest interest of the observations lies in the fact that fairly accurate determinations of stellar velocities are shown to be possible down to the eighth or ninth photographic magnitude, provided the spectra contain well defined lines. The field available for investigation by these instruments and methods is shown to be practically endless; and no doubt this field is fruitful beyond our most hopeful expectations. As soon as half-a-dozen of the great telescopes now engaging in this work have been made to produce accurate results, it will be highly desirable that a scheme of coöperation on a large scale be arranged and carried out by the interested observatories.

OBJECTS HAVING PECULIAR SPECTRA.[1]

A LIST of stars having peculiar spectra, and found by Mrs. Fleming from an examination of the Draper Memorial photographs, is given in the annexed table. The designation of the star, its approximate right ascension and declination for 1900, its catalogue magnitude, and a brief description of its photographic spectrum, are given in the successive columns of the table. The remarks following the table furnish additional details of the spectrum and, in some cases, a more accurate determination of the position as derived from a photograph, when the object is not a catalogue star.

TABLE I.

PECULIAR SPECTRA.

Designation	R. A. 1900	Dec. 1900	Mag.	Description
	h m	°		
....	0 56.0	−72 42	....	Type V. Gal. long. 268° 10′, lat. — 45° 15′
....	1 6.2	−73 44	.....	Gaseous nebula. Gal. long. 267° 29′, lat.—44° 9′
....	4 49.9	−69 21	.....	Gaseous nebula. Gal. long. 247° 21′, lat.—35° 41′
....	4 52.6	−69 33	.....	Gaseous neubla. Gal. long. 247° 31′, lat.—35° 24′
....	4 55.1	−69.21	.....	Gaseous nebula. Gal. long. 247° 13′, lat.—35° 14′
....	4 55.7	−66 26	.....	Type V. Gal. long. 243° 42′, lat.,—35° 50′
....	4 56.8	−66 32	.....	Gaseous nebula. Gal. long. 243° 48′, lat.—35° 42′
....	4 57 3	−66 33	.....	Gaseous nebula? Gal. long. 243° 48′, lat.—35° 39′
....	4 57.5	−68 35	.....	Gaseous nebula? Gal. long. 246° 15′, lat.—35° 12′
....	4 57.8	−68 33	.....	Type V. Gal. long. 246° 12′, lat.—35° 11′
....	5 0.4	−70 20	.....	Type I. $H\beta$ and $H\gamma$ bright.
....	5 3.0	−66 49	.....	Type V. Gal. long. 244° 0′, lat.—35° 3′
....	5 10.2	−69 0	.....	Type V. Gal. long. 246° 27′, lat.—34° 0′
....	5 10.3	−69 1	.....	Type V. Gal. long. 246° 28′, lat.—33° 59′
....	5 13.8	−67 20	.....	Type V. Gal. long. 244° 35′, lat.—33° 54′
....	5 14.8	−69 25	.....	Type V. Gal. long. 246° 52′, lat.—33° 31′
....	5 22.2	−68 3	.....	Gaseous nebula. Gal. long. 245° 8′, lat.—33° 3′
....	5 22.5	−68 4	.....	Gaseous nebula. Gal. long. 245° 9′, lat.—33° 1′
....	5 23.9	−71 43	.....	Tpye V. Gal. long. 249° 26′, lat.—32° 25′
....	5 24.6	−71 26	.....	Type V. Gal. long. 249° 5′, lat.—32° 24′
....	5 26.4	−67 35	.....	Type V. Gal. long. 244° 32′, lat.—32° 42′
....	5 27.1	−68 55	.....	Type V. Gal. long. 246° 6′, lat.—32° 31′
....	5 35.6	−67 39	.....	Gaseous nebula. Gal. long. 244° 32′, lat.—31′ 50′
....	5 36.2	−69 45	.....	Type I. $H\beta$, $H\gamma$, and $H\delta$ bright
....	5 36.8	−69 44	.....	Type I. $H\beta$, $H\gamma$, and $H\delta$ bright

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[1] *Harvard College Observatory Circular* No. 60.

TABLE I.—*Continued.*

Designation	R. A. 1900	Dec. 1900	Mag.	Description
	h m	°		
....	5 37.6	−69 30	.....	Type V. Gal. long. 246° 41′, lat.−31° 32′
....	5 37.7	−69 16	.....	Type V. Gal. long. 246° 25′, lat.−31° 32′
....	5 40.7	−69 27	.....	Type V. Gal. long. 246° 37′, lat.−31° 16′
....	5 40.9	−69 27	.....	Type V. Gal. long. 246° 37′, lat.−31° 14′
....	5 41.4	−69 43	.....	Gaseous nebula. Gal. long. 246° 55′, lat.−31° 11′ Lines λ 5007, $H\beta$, $H\gamma$, $H\delta$ and $H\epsilon$, bright
A. G. C. 8991	7 3.2	−23 41	6.3	Type I. $H\beta$ bright
Z. C. 10^h 1363	10 19.4	−59 8	8.8	Type I. $H\beta$ bright
Z. C. 10^h 2112	10 30.3	−47 53	9	Peculiar
C. P. D. − 58° 2845	10 49.7	−58 59	9.8	Type V. Gal. long. 256° 13′, lat.+0° 4′
C. P. D. − 61° 2577	11 39.6	−61 43	9.9	Type V. Gal. long. 262° 55′, lat.−0° 33′
Z. C. 11^h 3668	11 54.8	−58 2	9	Peculiar
....	13 26.4	−65 28	.....	Gaseous nebula. Gal. long. 274° 48′, lat.−3° 54′
−17° 3961	13 50.3	−17 45	8.0	Peculiar
−43° 9005	14 16.1	−43 41	10	Gaseous nebula. Gal. long. 287° 45′, lat.+15° 1′
Z. C. 14^h 970	14 16.9	−47 4	9.5	Type IV.
....	15 7.1	−59 28	.....	Type V. Gal. long. 287° 43′, lat.−2° 35′
C. P. D. − 65° 3171	15 46.7	−65 52	9.2	Peculiar
−40° 11127	16 58.1	−40 44	9.9	Gaseous nebula. Gal. long. 313° 11′, lat.−1° 4′
....	17 3.5	−55 16	.....	Gaseous nebula. Gal. long. 301° 55′, lat.−10° 22′
−49° 11366	17 14.6	−49 22	10	Peculiar. Gal. long. 307° 49′, lat.−8° 27′
Z. C. 17^h 1520	17 24.4	−51 0	8	Peculiar.
−33° 12168	17 26.5	−33 33	9.8	Type V Gal. long. 322° 18′, lat.−1° 35′
....	17 33.5	−57 52	.....	Peculiar.
....	17 38.1	−44 52	.....	Gaseous nebula. Gal. long. 313° 51′, lat.−9° 27′
A. G. C. 24406	17 52.7	−36 0	7.2	Type V. Gal. long. 320° 0′, lat.−7° 27′
....	17 52.8	−56 16	.....	Type I. $H\beta$ bright
−43° 12354	18 5.9	−43 43	10	Peculiar.
....	18 11.1	−46 2	.....	Gaseous neubla. Gal. long. 315° 31′, lat.−15° 7′
−16° 4904	18 24.6	−16 59	9.8	Type IV
....	18 27.9	−22 43	.....	Gaseous nebla. Gal. long. 338° 27′, lat.−7° 57′
−13° 5083	18 38.7	−13 20	9.1	Type IV
− 4° 4678	18 58.7	− 4 28	9.0	Type V. Gal. long. 358° 16′, lat.−6° 13′
− 9° 5069	19 11.0	− 9 14	10	Gaseous nebula. Gal. long. 355° 22′, lat.−11° 7′
−50° 12918	20 12.9	−50 8	10	Type IV

h m

0 56.0. Position for 1875, R. A. $= 0^h\ 55^m\ 10^s.3$, Dec. $= -72°\ 50'\ 18''$. This fifth type star is in the Small Magellanic Cloud, and is the only object of its class so far found in this region.

1 6.2. Position for 1850, R. A. $= 1^h\ 4^m\ 45^s.2$, Dec. $= -73°\ 59'\ 43''$. This nebula is in the Small Magellanic Cloud.

4 49.9. This, and the following twenty-seven objects are in the Large Magellanic Cloud. The number of stars of the fifth type, in this region, is thus increased from six to twenty-one.

4 57.3. A bright line appears near $H\beta$ in the spectrum of this faint object. In such cases, the only way to decide whether the object is a gaseous nebula, a star of the first type having the hydrogen line $H\beta$ bright, or a star of the fifth type, is to see if the wave-length of this line is greater than, equal to, or less

h	m	
		than that of $H\beta$. This is done by superposing a chart plate of the region on a spectrum plate, so that the images of adjacent stars on the former coincide with the hydrogen line $H\beta$ in the images on the latter plate. Owing to the faintness of this object and the small dispersion, it is difficult to determine the exact position of the bright line.
4	57.5.	See $4^h\ 57^m.3$.
5	40.7.	This object was announced as a gaseous nebula in *N. G. C.* 2081, *Circular* No. 19. An examination, by the method described above (see $4^h\ 57^m.3$), however, shows that the spectrum is of the fifth type.
7	3.2.	The bright hydrogen line in the spectrum of this star was found by Miss Cannon.
10	30.3.	*Z. C.* 10^h 2112. A broad dark band in this spectrum, of somewhat shorter wave-length than $H\beta$, appears to coincide with the bright band characteristic of spectra of the fifth type. In fact, the spectrum of this star resembles that of a star of the fifth type reversed upon a continuous spectrum.
11	54.8.	The spectrum of this star resembles that of *Z. C.* 10^h 2112.
13	26.4.	Position for 1875. R. A. = $13^h\ 24^m\ 41^s.8$. Dec. = — 65° 19′ 50″.
15	7.1.	Position for 1875, R. A. = $15^h\ 5^m\ 3^s.2$, Dec. = — 59° 22′ 27″.
15	46.7.	Spectrum continuous. $H\beta$, $H\gamma$, and $H\delta$, bright.
17	3.5.	Position for 1875, R. A = $17^h\ 1^m\ 26^s.0$, Dec. = — 55° 14′ 20″.
17	14.6.	The spectrum of this star resembles that of *Z. C.* 10^h 2112.
17	33.5.	Position for 1875, R. A. = $17^h\ 31^m\ 15^s.6$, Dec. = — 57° 50′ 57″. The spectrum of this star resembles that of *Z. C.* 10^h 2112. It also resembles that of the adjacent star A. G. C. 23935, announced as a variable in *Circular* No. 24.
17	38.1.	Position for 1875, R. A. = $17^h\ 36^m\ 18^s.8$, Dec. = — 44° 51′ 4″.
17	52.8.	Position for 1875, R. A. = $17^h\ 50^m\ 41^s.5$, Dec. = — 56° 16′ 23″.
18	5.9.	The spectrum of this star resembles that of *Z. C.* 10^h 2112.
18	11.1.	Position for 1875, R. A. = $18^h\ 9^m\ 12^s.9$, Dec. = — 46° 2′ 29″.
18	27.9.	Position for 1855, R. A. = $18^h\ 25^m\ 9^s.1$, Dec. = — 22° 44′ 44″.

The bright line $H\beta$ in the spectra of η *Centauri*, *A. G. C.* 17739, and κ *Apodis*, *A. G. C.* 20878, has been found to be variable, by Miss A. J. Cannon. The star *Z. C.* 18^h 1935, announced as of the fourth type in *Circular* No. 32, appears to have a spectrum of the same class as *Z. C.* 10^h 2112, described above.

EDWARD C. PICKERING.

July 6, 1901.

LATITUDE AND LONGITUDE OF THE YERKES OBSERVATORY.[1]

THE latitude and longitude of the Yerkes Observatory were first determined by Mr. W. H. Wright in 1897, and the approximate values

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[1] *Yerkes Observatory Bulletin* No. 18.

obtained were published in *Bulletin* No. 2. In the autumn of 1900, through the courtesy of the Superintendent of the United States Coast and Geodetic survey, Assistants C. H. Sinclair (chief of party) and O. B. French were detailed to determine the latitude of the Observatory and the difference in longitude between our transit room and the Coast Survey Station at St. Louis.

A full description of Zenith Telescope No. 4, and of the methods of observation and reduction employed in the determination of the latitude by Mr. French, may be found in *Report of the United States Coast and Geodetic Survey*, 1897–8, Appendix No. 7 (fourth edition), pp. 342, 347–350, 354–363, etc. The determination of the micrometer value by observations of λ *Ursae Majoris* on October 26 gave for the value of one turn 44″.60. The value as afterward computed from the latitude observations themselves by the method indicated on page 370 of the Appendix was 44″.6164. The column headed *Mm.* in the table shows the correction to the results from separate pairs, due to the change from the value 44″.60 to the value 44″.6164. The results for each pair of stars employed are given in the following table:

LATITUDE OF THE YERKES OBSERVATORY.

No. of pair	Catalogue Nos., *Gr. 10 Yr.* 1880	φ	Δφ	*Mm.*	φ Corrected for micrometer	v	n	w	wφ	Δφ
		° ′ ″	″	″	° ′ ″					
1	3534—3548	42 34 12.47	+0.17	+0.17	42 34 12.64	−0 01	6	29	18.56	0.00
2	3578—3587	13.13	− .49	− .13	13.00	− .37	6	19	19.00	− .36
3	3595—3610	13.22	− .58	− .08	13.14	− .51	6	29	33.06	− .50
4	3617—3631	12.73	− .09	− .14	12.59	+ .04	5	22	12.98	+ .05
5	3651—3662	12.07	.57	− .18	11.89	+ .74	5	20	−2.20	+ .75
6	3671—3677	13.00	− .36	− .15	12.85	− .22	5	28	23.80	− .21
7	3684—3724	12.30	+ .34	+ .06	12.36	+ .27	6	29	10.44	+ .28
8	3758—3760	13.15	− .51	+ .03	13.18	− .55	5	19	22.42	− .54
9a	3740—3783	12.46	+ .18	− .12	12.34	+ .29	1	12	4.08	+ .30
9	3758—3787	12.55	+ .09	+ .10	12.65	− .02	5	19	12.35	− .01
10	3806—3815	12.36	+ .28	+ .05	12.41	+ .22	5	14	5.74	+ .23
11	3820—3827	12.77	− .13	− .21	12.56	+ .07	6	14	7.84	+ .08
12	3806—3827	12.26	+ .38	− .04	12.22	.41	5	14	3.08	+ .42
13	3815—3820	13.02	− .38	− .13	12.89	− .26	5	14	12.46	− .25
14	3879—3891	12.63	+ .01	− .04	12.59	+ .04	6	29	17.11	+ .05
15	3915—3925	12 36	+ .28	+ .14	12.50	+ .13	6	29	14.50	+ .14
16	3939—3974	12.63	+ .01	+ .03	12.66	− .03	6	16	10.56	− .02
17	3995—4003	12.51	+ .13	− .04	12.47	+ .16	6	4	1.88	+ .17
18	4003—4018	12.76	− .12	− .07	12.69	− .06	6	19	13.11	− .05
19	4030—4044	12.65	− .01	− .09	12.56	+ .07	6	29	16.24	+ .08
20	19—52	12.82	− .18	+ .07	12.89	− .26	6	19	16.91	− .25
21	37—52	12.13	+ .51	+ .21	12.34	+ .29	5	19	6.46	+ .30
22	72—86	12.73	− .09	+ .01	12.74	− .11	5	28	20.72	− .10
23	114—127	12.57	+ .07	+ .09	12.66	− .03	5	22	14.52	− .02
24	154—157	12.71	− .07	+ .09	12.80	− .17	4	26	20.80	− .16
p=25		42 34 12.64	+2.97 −3.01	m=0.0082	42 34 12.63	−2.60 +2.73	132	522	336.42	

Probable error of a single observation $= e = \sqrt{0.0518} = \pm 0''.228$.

$$e_p^2 = 0.037 \qquad e^2 = 0.011\,.$$

$$e^2_{\frac{**}{2}} = 0.037 - 0.011 = 0.026\,.$$

$$\text{Latitude Yerkes Observatory} = 42^\circ\ 34'\ 12''.00 + \frac{336.42}{522}$$

$$= \mathbf{42^\circ\ 34'\ 12''.64 \pm 0''.038}\,.$$

In the determination of the longitude, Transit No. 18 was mounted on the transit pier of the Yerkes Observatory, at a point 264 feet 5 inches ($=0^s.235$) east of the center of the 40-inch equatorial pier. At St. Louis, Transit No. 19 was mounted on the brick pier erected by Professor Woodward in the east end of the Observatory of Washington University. This station is 1.2 feet ($=0^s.001$) west of the Coast Survey Station of 1881. The results of the observations are given in the following table:

DIFFERENCE OF LONGITUDE BETWEEN ST. LOUIS, MISSOURI, AND THE YERKES OBSERVATORY, WILLIAMS BAY, WISCONSIN.

Date 1900	Observers at		Mean of W. and E. Signals	Personal Equation	Difference of longitude		Transmission time
	St. Louis	Yerkes Obs.					
			m s	s	m s	s	s
Oct. 8	O. B. French	C. H. Sinclair	6 36.013	+0.205	6 36.218	+0.031	0.067
9			.013		.218	+ .031	.046
10			.078		.283	− .034	.040
12			.072		.277	− .028	.042
			6 36.044				
13	C. H. Sinclair	O. B. French	.473	−0.204	.269	− .020	.033
14			.414		.210	+ .039	.053
15			.445		.241	+ .008	.034
16			.482		.278	− .029	.045
			6 36.453		6 36.249	±0.009	0.044

St. Louis (1881)—Yerkes Observatory Transit (1900) $= 6^m\ 36^s.248 \pm 0^s.009$

Longitude St. Louis (1881), latest adjustment	$6^h\ 00^m\ 49^s.256$
Longitude Yerkes Observatory Transit	5 54 13.008
Longitude Yerkes Observatory 40-inch Equatorial	**5 54 13.243**

I take pleasure in expressing the thanks of the Yerkes Observatory to Superintendents Pritchett and Tittmann and to Assistants Sinclair and French, of the Coast and Geodetic Survey, for the important results of this admirably conducted campaign.

GEORGE E. HALE.

August 13, 1901.

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OBSERVATIONS AND EPHEMERIDES OF THE VARIABLE STAR *Y CYGNI.*

By N. C. DUNÉR.

THE manner in which I determined the first elements of the orbit of the Algol star *Y Cygni*, together with the numerical values of the elements as computed from the minima of the years 1886 to 1898, have been published in the ASTROPHYSICAL JOURNAL, **11**, 175–191, 1900. The following even and odd minima of the star were observed[1] during the autumn of 1900

Epoch	Minimum (Gr. M. T.)					O.—C.	Observer
3356	1900	Sept.	15^{d}	9^{h}	33^{m}	-13^{m}	D
3370		Oct.	6	9	8	− 1	B
3392		Nov.	8	8	1	−11	D
3400			20	7	49	− 2	B
3410		Dec.	5	7	26	0	B
3416			14	7	11	+ 1	B
3422			23	6	41	−13	D
3491	1901	April	5	10	38	−24	D
3495			11	10	46	− 4	D
3503			23	10	5	−23	D
3505			26	10	12	−11	D
3507			29	9	57	−21	D

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[1] The minima in 1900 published in *A. N.* No. 3720 are corrected for the equation of light, which is not the case with the observations below.

and spring of 1901 by myself and Dr. Bergstrand, now second astronomer at this Observatory. I have added the difference between the calculated and the observed dates.

From these observations we obtain the following two normal minima and normal deviations.

Epoch	Normal Minimum	O.—C.
3396	$1885.0+5431^{d}.331$	$-0^{d}.004$
3501	$1885.0+5588.426$	-0.012

These normal minima have been computed from 1885.0, in agreement with the principal epoch t_0 but in contrast to the earlier ones. It will be seen that these normal minima, which were unknown in the derivation of the elements, agree better with them than do several of the normal minima employed. Under these circumstances I have not thought it yet necessary to attempt the correction of the elements, but have merely computed the following ephemeris for 1902.

Even Minima						Odd Minima					
Epoch	Minimum (Gr. M. T.)					Epoch	Minimum (Gr. M. T.)				
3676	1902	Jan.	7^{d}	19^{h}	19^{m}	3675	1902	Jan.	6^{d}	3^{h}	7^{m}
3696		Feb.	6	18	24	3695		Feb.	5	2	16
3716		Mar.	8	17	30	3715		Mar.	7	1	25
3736		April	7	16	35	3735		April	6	0	34
3756		May	7	15	40	3755		May	5	23	23
3776		June	6	14	46	3775		June	4	22	53
3796		July	6	13	56	3795		July	4	22	2
3816		Aug.	5	12	56	3815		Aug.	3	21	11
3836		Sept.	4	12	0	3835		Sept.	2	20	20
3856		Oct.	4	11	5	3855		Oct.	2	19	30
3876		Nov.	3	10	11	3875		Nov.	1	18	39
3896		Dec.	3	9	16	3895		Dec.	1	17	48
3916			33	8	20	3915			31	16	58

During the observations in 1900 and 1901 the duration of the even minima was considerably longer than that of the odd minima, whence it now appears almost certain that there is hardly any further justification for the doubt expressed at several places in the article referred to as to the correctness of my assumption that the principal epoch in 1885 coincided with the perihelion passage. In general, the elements therefore appear to be correct in this respect also.

UPSALA, July 1, 1901.

PECULIARITY OF FOCAL OBSERVATIONS OF THE PLANETARY NEBULÆ AND VISUAL OBSERVATIONS OF *NOVA PERSEI* WITH THE FORTY-INCH YERKES TELESCOPE.

By E. E. Barnard.

As is well known, and as I have shown further in *Monthly Notices of the Royal Astronomical Society*, Vol. LX, January, 1900, pp. 255–557, the focus of a large refracting telescope for the planetary nebulæ is something like 0.25 inch farther away from the object-glass than for a fixed star. With a high power on the 40-inch Yerkes telescope this difference of focus for a star and a gaseous nebula is very striking. It is so decided that if one should first focus carefully on a star and then examine a planetary nebula with the same adjustment, he would see only the coarser details. A re-focusing on the nebula would reveal details he would not ordinarily suspect. This also holds in photographing these bodies, so that a focus which (with a color-screen) would give a perfect image for a star with the 40-inch would not clearly show the details of a planetary nebula. By setting the plate from a quarter to a third of an inch farther out than for the star the details of the nebula are beautifully shown while the stars are but ill-defined, and the fainter ones entirely lost.

This peculiarity of a refracting telescope is a natural consequence of the difference in the spectra of the stars and the planetary nebulæ, as has been pointed out to me by Professor Hale.

It may be interesting to copy here the table showing these differences of focus printed in *Monthly Notices*, Vol. LX, to which are added several other objects and more observations. These were all determined with the 40-inch.

TABLE OF FOCUS FOR THE PLANETARY NEBULÆ.

N. G. C.	α 1860.0	δ 1860.0	Neb.—Nucl.	Neb.—Star.	Nucl.—Star.
			in.	in.	in.
1535	4^h 7^m 44^s	−13° 6′	+0.23	+0.28	+0.05
2392	7 20 53	+21 12	+0.29	+0.32	+0.03
3242	10 18 2	−17 56	+0.12	+0.10	+0.04
6543	17 58 36	+66 38	+0.16	+0.21	+0.05
6720 (*M* 57)	18 48 23	+32 51	+0.20	+0.30	+0.10
6826	19 41 2	+50 11	+0.22	+0.21	−0 01
6905	20 16 9	+19 40	+0.19	+0.33	+0.15
7009	20 56 33	−11 55	+0.19	+0.23	+0.04
7662	23 19 11	+41 45	+0.06	+0.20	+0.14
			+0.18	+0.25	+0.06

No. 1535 —	Two	nights'	observations.	
2392	Seven	"	"	
3242	Five	"	"	
6543	Two	"	"	
6720	Two	"	"	
6826	Two	"	"	for nucl.—star, both the same.
6905	Two	"	"	
7009	Two	"	"	for neb.—star.
7662	Four	"	"	" " "

The *Orion* nebula gave nebula — star = + 0.22 inch.

Nova Aurigae is a striking example of this peculiarity. Recent observations with the 40-inch show that it has declined in the past few years to the thirteenth magnitude. With as faint an object as this the difference of focus between it and a star is decided, the *Nova* being best seen with a focus about one-third inch farther out.

This is shown by the following observations for focus on Nov. 3, 1900:

	in.	
Focus on *Nova Aurigae* - -	2.43	(3 obs.)
Focus on star - - - - -	2.16	(3 obs.)
Nova—star - - -	+0.27	

From the above table it would appear that if a planetary nebula were so minute as to present no appreciable disk in the telescope its nebulous character should still be recognizable without the spectroscope by this peculiarity in its focus.

No. 7662 has been observed quite a number of times with the micrometer for position of its nucleus. Sometimes the central star was very faint and difficult, while at other times, apparently as favorable, it has been an easy object. This has led me to suspect it of variation, but I have not yet been able to confirm the supposed variability.

In some respects No. 2392 is the most remarkable of these objects as seen with the great telescope, in which it is very beautiful. The following description, with some changes, is from *Monthly Notices*, LX, for January, 1900:

A bright star of the ninth magnitude in (but not exactly central) a brightish ring which is oval in form and almost incomplete in its southern part. This ring, which is well defined inside and out, is surrounded by a vacuity, and this in turn by a broad ring of light less intense than the inner ring, and with a distinct break in it north preceding. This ring breaks up into a clouded or unequal surface, and is very irregular on its inner edge but fairly uniformly circular on the outside. The inner ring is filled with nebulous light, which has a bright spot in it south preceding the nucleus. I have found another excessively difficult star within the inner ring north of the bright star; this minute object comes to a focus with the nebula and not with the central star. It is therefore, doubtless, a small condensation of the nebula not so far advanced in stellar condition as the bright central star. When the atmospheric conditions permit, this beautiful nebula is best seen with a very high power — it stands magnifying well. It must also be very carefully focused — on the nebulosity itself — before the details described are seen. With a low power it is quite different, for it then appears as a bright yellowish star in a circular disk of light, surrounding which is a perfectly circular vacuity, and surrounding this vacuity is a symmetrical circular ring not so bright as the central disk. This, I suppose, is the general impression it gives when examined casually. But with the higher powers it loses much of this symmetry and becomes more complex, as already described.

In the article referred to in *Monthly Notices*, LX, the faint additional star in the central ring is described as being south of the central star. It is north.

The focus determinations for this nebula are the best of any in the list, as they depend on seven nights' observations.

In No. 6905 the central star is faint, and there is not much detail to focus on. A note says: "there seems to be some detail in the nebula, possibly spiral in form, but mainly an inequality of its light."

This brings me to the purpose of this note, some peculiarities of *Nova Persei*. I was absent with the eclipse expedition to Sumatra when this star appeared, and did not see it during its great brilliancy. It had declined to the sixth or seventh magnitude when I first saw it in August. Like its predecessors, it shows, in the fading of its light, the nebular spectrum, and seems, therefore, to have become a gaseous nebula.

To test the nebulous character of this object visually I have carefully examined it with the 40-inch, both for nebulosity and for peculiarity of focus. I have not been able with certainty to see any nebulosity. A careful series of focus readings on two dates, comparing it with the white star *DM.* $+43^{\circ}.732$ (7.5 magnitude; 1855.0: $3^{h}\,18^{m}\,45^{s} + 43^{\circ}\,14'.6$), does not show any difference in focus between the star and the *Nova*.

Following are the measures for focus:

1901. August 12. *Nova*, . . 2.25 in. (4 obs.) } power 700
7.5 mag. star, 2.26 in. (4 obs.) }

Nova — 7.5 mag. star = — 0.01

1901. September 3. *Nova*, . . 2.29 in. (5 obs.) } power 1300
7. 5 mag. star, 2.30 in. (5 obs.) }

Nova — 7.5 mag. star = — 0.01

This difference, though it is the same in the two sets of observations, doubtless does not mean anything. The readings are on a scale of inches engraved on the tube. The tube lengthens and shortens with changes of temperature, which causes the difference in the two sets of readings.

This, of course, does not necessarily imply the absence of nebulosity in the *Nova*. It may mean that the visual light is so predominant as to mask the usual effect produced by a nebula in its focus. Its action is therefore more like that of the nucleus of a planetary nebula. When the *Nova* has faded greatly it will be interesting to see if its focus becomes like that of the planetary nebulae.

On August 12 the seeing was unusually good. Examining the *Nova* with high powers, I was struck with its appearance. It was brighter than the star, but under the high magnifying powers its light was strikingly dull, having more the appearance of planetary light. This was so decided that had I been examining the stars in that region I should at once have singled out the *Nova* as different from any of the stars. The spurious disk appeared much duller and somewhat larger than that of a star, and of a slight yellowish color.

This peculiarity has been seen several times since.

On several occasions a faint companion has been visible north following *Nova Persei*. On September 16 and 23, 1901, its position was measured.

NOVA PERSEI AND *a*.

1901.709	63°5	Dist. 19'6
.729	66.8	19.2
1901.719	65.1	19.4

It is about 15^{m} and very difficult to measure.

Five other stars of about the thirteenth magnitude were also measured.

NOVA PERSEI AND *b*.

1901.578	116°21	102'55	13 mag.
.693	116.14	102.57	
.709	116.33	102.50	
1901.66	116.23	102.54	

NOVA PERSEI AND *c*.

1901.578	211°20	124'25	13 mag.
.693	211.34	124.20	
.709	211.28	124.18	
1901.66	211.27	124.21	

NOVA PERSEI AND *d.*

1901.732	303°.48	164″.62	13 mag.
.749	303.67	165.03	
.751	303.62	165.25	
1901.74	303.59	164.97	

NOVA PERSEI AND *e.*

1901.732	63°.07	158″.55	12.7 mag.
.749	63.10	158.76	
.751	63.07	158.51	
1901.74	63.08	158.61	

NOVA PERSEI AND *f.*

1901.732	292°.98	181″.70	12.8 mag.
.749	293.07	181.82	
.751	293.02	181.78	
1901.74	293.02	181.77	

All the observations, except for *a*, are double distances.

On September 16 at 14^h the *Nova* was carefully compared in brightness with the stars *DM.*+43°.720, *DM.*+43°.730, and *DM.*+43°.732. The result for the *Nova* was 7.3 magnitude on the *DM.* scale of magnitudes.

Having seen the announcement by M. Flammarion and Dr Max Wolf of the discovery of a nebula about *Nova Persei* I carefully looked for it with the 12-inch refractor on the night of September 20. The following note was made:

> Examined *Nova Persei* between 13^h and 14^h with the 12-inch, using a low power (about 90 diameters). I could not see with certainty anything of the nebula encompassing this star as described by Dr. Max Wolf in *A.N.*, 3736. The sky and seeing were good with the low power. The region of the *Nova* for some distance seemed to have more scattered light than that farther away, while the region of the 7.5 mag. star *DM.*+43°.732, about 2½ minutes preceding and 10′ south, by contrast was free of this peculiarity.

I have since that date examined the *Nova* with the 40-inch for the nebulosity after having seen Mr. Ritchey's excellent photograph of it. Knowing the exact positions of the various parts of the nebula, these were perhaps seen, but the night was not sufficiently pure to make certain of it. This nebulosity is, of course, vastly better suited for the photographic plate than for visual observations with any telescope.

During the observations of *Nova Persei* a nebula was found which from its proximity to the new star is worthy of record. It lies one degree south of the *Nova*.

This nebula was measured with reference to a twelfth magnitude star.

TWELFTH MAGNITUDE STAR AND NEBULA.

1901.735 $4^{\circ}.7$ (3) $33'.9$ (2)

The twelfth magnitude star was measured with reference to the 7.8 mag. star *DM.*$+42^{\circ}.776$ whose place for 1855.0 is

$$\alpha=3^h\ 22^m\ 25^s.5\quad \delta+42^{\circ}\ 15'.2$$

Twelfth mag. star precedes 7.8 mag. star $0^m\ 55^s.69$ (14)
" " " north of 7.8 " " $1'\ 55''.61$ (2)

This gives for the position of the nebula

$$1860.0\quad \alpha=3^h\ 21^m\ 50^s.5\quad \delta=+42^{\circ}\ 18'.7$$

It is about 13.5 mag., a half minute in diameter and somewhat brighter in the middle ; and is perhaps irregular in form.

YERKES OBSERVATORY,
September 13, 1901.

NOTE.—A photograph of the spectrum of *Nova Persei*, taken on September 24 by Mr. Walter S. Adams with a one prism spectrograph attached to the 24-inch reflector of the Yerkes Observatory, indicates that the continuous spectrum in the yellow and green is relatively stronger than in the case of the planetary nebulae. This may perhaps be sufficient to account for the peculiarities of focus observed by Professor Barnard.— ED.

OBSERVATIONS OF THE EARLIER SPECTRUM OF *NOVA PERSEI.*

By WALTER S. ADAMS.

THE photographic study of the spectrum of *Nova Persei* was commenced at the Yerkes Observatory by Mr. Ellerman on February 24, and continued when weather permitted until May 1, at which date the spectrograph was dismantled preparatory to being adapted for work with a reflecting telescope. Of the series of plates thus obtained rather more than one-half were photographed with a dispersion of three prisms, and hence are comparatively limited in their range, and better suited for the detailed study of the structure within individual lines than for the direct determination of wave-lengths. The remaining plates were secured with a one prism spectrograph attached to the 40-inch refractor, and cover in general the extent of spectrum from D to λ3700. Seventeen of these have been measured in whole or in part, and it has seemed best to give a summary of the results found, without in this place entering into minute details, or considering the conditions necessary in the star to give rise to the extraordinary variations observed. All of the plates measured were obtained by Mr. Ellerman, who was assisted in guiding, at times a task of no little difficulty on account of the low altitude of the star, by Mr. Sullivan.

A statement of the changes which occurred in the spectrum of *Nova Persei* up to April 8 has already been published.[1] Since that time it has varied between two general types. The first, which Pickering[2] calls the normal, and which seems to coincide with the periods of greatest brightness of the star, has a relatively strong continuous spectrum, and the hydrogen lines in their normal positions. The second type is characterized by a relatively weak continuous spectrum, the great strengthening of various bright lines, and the lateral extension and hence apparent displacement of some of the hydrogen lines. In addition to these broad variations there are many minor ones, some of which appear to depend upon the type of spectrum present, others to be quite independent of it. The more important of these variations will now be considered in detail.

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[1] ASTROPHYSICAL JOURNAL, **13**, 238, April, 1901.

[2] *Harvard College Observatory Circular* No. 59. See also Sidgreave's paper: *The Observatory*, Vol. XXIV, No. 305, May, 1901.

I. VARIATIONS IN THE BRIGHT HYDROGEN LINES.

Hι is clearly visible upon one of the earlier plates at λ3771. In the general falling off of intensity in the ultra-violet, however, it soon becomes too faint for measurement, and then disappears.

Hθ has been measured upon three of the early plates, giving a wave-length 3800.

Hη is shown upon the plates of February 25 to be accompanied by a bright band upon its less refrangible side. On February 27 this has united with *Hη* to form a single band with center at λ3846, and remains in this position so long as the band is visible at all.

Hζ is probably the most remarkable line in the entire spectrum. After remaining constant in position and width until March 15, it suddenly adds a broad violet component in the interval between March 15 and 22, thus greatly increasing its normal width. At the same time, however, its red edge begins to decrease in intensity, the loss continuing while the violet edge remains constant until the original width is nearly reached. The result is a very great displacement of the center of the line toward the violet, amounting in full to over twenty tenth-meters. It seems probable that in this new position the line is not *Hζ* at all, but belongs to some new element, perhaps helium, which has a strong line at λ 3888.8. The fact remains, however, that upon two plates, those of April 8 and 18, in which the type of spectrum seems to have returned to the normal, *Hζ* is seen in its original position, and apparently of its original width, although the band is too weak to admit of measurement.

The following table gives the position of the center, and of the violet and red edges of *Hζ*, together with its width in tenth-meters.

Date	Center	Violet edge	Red edge	Width in t.m.	
February 27–March 15....	3894	3877	3911	34	7 plates
March 28	3881	3855	3907	52	1 plate
April 3	3879	3855	3905	50	2 plates
April 15–17	3874	3855	3893	38	2 plates

A sequence of order of brightness among the other hydrogen lines seems to be maintained upon the earlier plates. By April 4, however, *Hγ* has become fully as strong as *Hβ*, and appears to continue so throughout the remainder of the observations. In general it may be said that upon plates which exhibit the peculiar type of spectrum the bright hydrogen lines show a much more nearly uniform intensity than upon plates where the spectrum is normal. In view of the gradual falling off of intensity in the ultra-violet this fact is somewhat remarkable.

In addition to intensity changes there are variations in the shadings of several of the hydrogen lines, particularly *Hδ* and *Hγ*. The photographs of February 27 show *Hδ* to fall off very gradually toward the red owing to its union with a bright shade whose red edge falls at λ 4146. This shade begins to decrease in intensity, and by March 22 has become incapable of measurement, thus leaving the red edge of *Hδ* comparatively sharp. In distinct contrast to the behavior of *Hδ* is that of *Hγ*. Until March 22 its red edge remains fairly distinct; on March 22 there are traces of a faint bright shade forming close to its red edge, and on March 28 this has united with *Hγ*, giving a very broad and strong band whose red edge falls at λ 4391. This band appears to be a further characteristic of the peculiar type of spectrum, as it appears upon all plates showing such a spectrum, while on the plates of April 8 and 18 it is absent, or, at any rate, very greatly weakened. A maximum in this red component of *Hγ* falls at λ 4387, and is probably the line observed by Pickering at λ 4384.

II. VARIATIONS IN THE DARK HYDROGEN LINES.

On February 24 the dark hydrogen lines are visible as faint diffuse shades on the more refrangible side of the bright bands. These are hardly to be seen on February 27, but from that time appear to increase in intensity. Upon the plates of February 28 they are clearly visible, particularly $H\delta$ and $H\gamma$, and by March 4 have become strong, with $H\delta$ showing traces of being double. The greatest intensity seems to be reached on March 11, when all the lines are very prominent and are double, with the distance between the components increasing toward the violet with the increasing dispersion. The more refrangible component then begins to weaken, the difference of intensity showing clearly upon the plates of March 15. On March 22 this component has entirely disappeared, and the less refrangible one has become much fainter. Finally by March 28 both components have vanished, and the bright hydrogen lines are joined with the faint bright bands hitherto separated by these dark lines, thus giving an uninterrupted shading to the violet.

III. VARIATIONS IN K.

The earliest plates show K as a broad bright band of about the same intensity of $H\epsilon$, and slightly more intense than $H\zeta$, with a prominent maximum at λ 3937, and a faint dark line on the more refrangible side of this. The dark line appears to follow the behavior of the dark hydrogen lines, increasing in strength until March 11, when it is a noticeable feature of this part of the spectrum, and then gradually fading, until on March 22 it has become invisible. The bright band upon which it is projected, after remaining fairly constant until March 11, also follows the course of the dark hydrogen lines, and has become extinct on March 22. This fact has already been noted by Sidgreaves.

IV. VARIATIONS IN BANDS λ4928 AND λ5020.

The intensity of these two bright bands, besides being greatly influenced by the general falling off in the spectrum to the red of $H\beta$, also exhibits considerable relative changes. Of nearly equal strength on February 24 they continue approximately so until the change of spectrum occurs between March 15 and 22. After this change λ5020 is much brighter than λ4928, although both have become greatly weakened in absolute intensity. This weakening is so great that after March 28 little more than traces of λ4928 can be seen, while upon plates showing the normal spectrum, that is, those of April 8 and 18, λ5020 also disappears.

In addition to changes of intensity, however, there occurs what appears to be a displacement of the center of λ5020 by some 12 tenth-meters toward the violet. As in the case of $H\zeta$ this probably takes place through addition of an extension on the violet edge, and a contraction of the red edge, but here the two processes seem to be much more nearly synchronous, as is shown by the comparatively slight changes in width.

The following table illustrates this fact:

Date	Center	Violet edge	Red edge	Width	
February 28–March 6	5022	5004	5041	37	7 plates
March 15	5019	5000	5036	36	1 plate
March 28	5013	4993	5034	41	1 plate
April 3–26	5010	4989	5033	44	4 plates

V. VARIATIONS IN *b*.

The earliest plates of the series show *b* as a strong band comparable with $H\gamma$ in brightness. It begins to fall off rapidly, however, and on March 15 is but little brighter than λ5020. On March 28 barely a trace is visible, and after that date it is not seen.

VI. VARIATIONS IN THE REGION λ4470 TO λ4740.

This part of the spectrum probably exhibits more variations than any other, both as regards intensity and position of the lines. Previous to the general change of type it may in general be said to consist of three very broad bright bands lying against a strong background of continuous spectrum. These bands extend from λ4468 to λ4686, and are divided by narrow dark breaks at λ4529–4537 and λ4604–4615. Beyond λ4686 occur various slight shades and maxima, notably a maximum at λ4721, but their study is difficult on account of the great intensity of the plate in this region. The three bands begin to break up, however, even before the main change of spectrum takes place. A dark break forms at λ4484–4504, and a maximum at λ4575. Furthermore, as early as March 4 there are traces of the formation of an extension upon the violet edge of λ4470. This remains comparatively faint until the change of type occurs, then increases very greatly in intensity, and, joining the adjacent shade, makes up a bright band extending from λ4456 to λ4491, and probably representing the helium line λ4472. On March 28 this band is fully as strong as *Hε*. A faint shade is present at λ4505–4544, and a somewhat stronger one at λ4556–4590, with a maximum at λ4563. A remarkable feature of this last shade is the displacement of its red edge from λ4604 to λ4590. The agreement of this displacement of 14 tenth-meters with that of 12 tenth-meters on the violet edge of λ4470 (from λ4468 to λ4456) would almost seem to argue for a connection between the two.

At the same time that these changes take place among the more refrangible bands the band λ4615–4686 begins to break up and extend. A dark break forms at λ4659 and extends as far as λ4672, while a faint shade upon its red side gradually increases in intensity until, with the remaining portion of the original bright shade, it forms a strong band extending from λ4672 to λ4743, and having an intense maximum at λ4689. The three bands λ4456–4491, λ4615–4659, and λ4672–4743 are the most striking features of this part of the spectrum of the later type, and vary considerably in intensity. On March 28 they are all about equal; on April 3 λ4615–4659 is the strongest of all. The first of the three, λ4456–4491, then seems to lose in intensity, and does not again become equal to either of the other two. On several plates, particularly those of April 29 and May 1, these two are about equally intense, and fully as bright as *Hγ* or *Hβ;* that is, are among the brightest bands in the entire spectrum. It should be noted of band λ4672–4743 that its composite character is noticeable upon several plates, the darkening between its parts showing especially clearly on the plates of April 22 and 24.

In addition to this discussion of the lines which occur on nearly all the plates, mention may be made of a few which have been seen upon but one or two. Of these a bright band with a center estimated at λ4960 is the most important. It makes its appearance upon a plate taken April 19, and is fairly prominent upon one of April 25. Unfortunately the series of photographs ends too early to admit of following its course very far. It is probably the nebula line λ4959. The dark line noted by Pickering at λ3865 is seen on a plate of April 8. I may also call attention at this point to a possible slight displacement of the center of $H\epsilon$ which seems to occur at the time of change of spectrum between March 15 and 22. The mean of seven plates

No. of plates	Part of line	λ	Substance	Remarks
3		3800	$H\theta$	
6		3846	$H\eta$ + (?)	Center of band formed by union of $H\eta$ and another band
2		3874	$H\zeta$	See Section I
2		3879		
1		3881		
7		3894		
7		3935	*K*	
7	Maximum	3937		
7		3973	$H\epsilon$	
6		3970		
3	Maximum	3973		
6		4029	*He*	
5		4067		
15		4105	$H\delta$	
7	Red edge	4146		Perhaps the red edge of the *He* line λ4121
8		4179		
9		4235	*Fe* (?)	

No. of plates	Part of line	λ	Substance	Remarks
8		4300		
14		4345	$H\gamma$	
6	Maximum	4382	*He*	
3		4387		
3		4408		
8		4474	*He*	See Section VI
7	Violet edge	4468		There is a slight dark break at λ 4484–4504
4	Red edge	4529		
4		4524		
3	Maximum	4563	*Ti* (?)	
6	Maximum	4573		
4		4575		
7	Red edge	4604		
13	Violet edge	4615		See Section VI
3		4636		
4	Red edge	4686		
2	Maximum	4689		Perhaps the nebula line
4		4707		
3	Maximum	4721	*He* (?)	
4		4820	*Fe* (?)	
14		4864	$H\beta$	
4	Red edge of maximum	4917	*He*	
10		4928		
4		5010	*He*	See Section IV
1		5013		
1		5019		
7		5022		
10		5174	*Mg*	
3		5237	*Fe* (?)	
3		5277		
8		5319	*Fe*	

previous to the first date gives as the center of this band λ 3973: the mean of six plates after the second date λ 3970. The disappearance of the dark hydrogen lines may, however, influence these measures somewhat.

In the above table are given the wave-lengths of bright lines measured upon three or more plates, together with some of the most probable identifications. The number of plates measured is given in the first column, and the part of the line to which the wave-length refers in the second column. When no statement is made the center is understood.

The comparison spectrum employed in all of these measures is that of titanium. Several lines lying to the red of those given might be added, but their wave-lengths would be subject to considerable errors of extrapolation, and hence it has seemed best not to include them in the table.

YERKES OBSERVATORY,
July, 1901.

PLATE VII.

FIG. 1.—PHOTOGRAPH MADE WITH TWO-FOOT REFLECTOR.

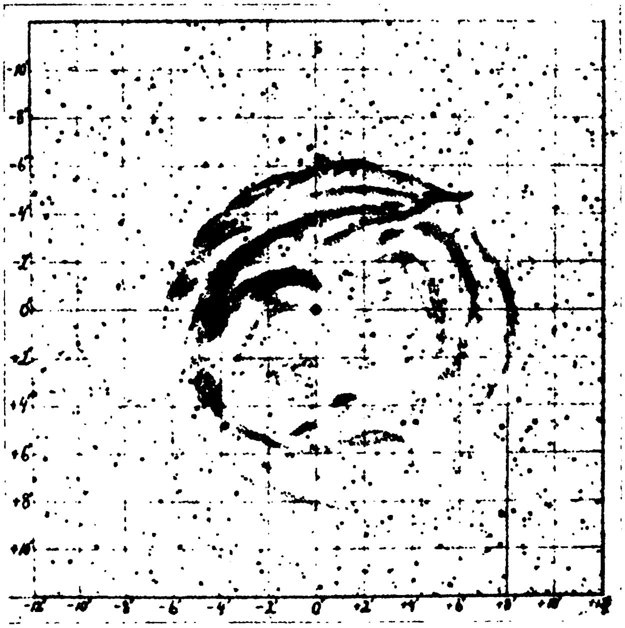

FIG. 2.—DIAGRAM FROM ORIGINAL NEGATIVE.

NEBULOSITY AROUND *NOVA PERSEI.*

By G. W. RITCHEY, Yerkes Observatory.

NEBULOSITY ABOUT *NOVA PERSEI.*

By G. W. RITCHEY.

On the night of September 20, 1901, the region of *Nova Persei* was photographed with the two-foot reflecting telescope of this Observatory, and a fairly satisfactory negative of the spiral or annular nebula surrounding the *Nova* was obtained.

The telescope mirror has a focal length of 93 inches, and on this occasion an aperture of 22 inches was used, so that the ratio of focal length to aperture was nearly as 4¼ to 1. The silver surfaces of the large mirror, and of the flat, are nearly new and are in fine condition. The night was fairly, but not extremely, transparent. A Cramer "Crown" plate was used, of sensitiveness nearly twice as great as the average for such plates, and an exposure of three hours and fifty minutes was given. With these favorable conditions and with the great concentration given by the short focus mirror the image of the nebula on the negative is very faint; only the streamer or wisp to the south of the *Nova* is strong; this part of the nebula was photographed earlier by Dr. Max Wolf.[1]

The reflector photograph is free from the false penumbra about the *Nova* which is shown on photographs of this object obtained with refracting instruments. The image of the *Nova* in the reflector negative with nearly four hours' exposure is about 20″ in diameter and there is little or no halo of nebulosity immediately about it; two moderately dense wisps of nebulosity, however, extend from the *Nova* toward the west, curve toward the north, and merge into the convolutions of the nebula. As will be seen from the accompanying illustrations, Plate VII, the nebula is of quite complex form; whether it is spiral or consists of several annuli with interlacing branches cannot now be stated; possibly a stronger negative may make this clear.

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[1] *A. N.*, **156**, 254.

The greater part of the delicate structure shown on the negative is so faint that there was no hope of being able to reproduce this well in the half-tone plate. Accordingly a diagram was hastily prepared which shows the approximate position of nearly all of the faint nebulosity visible on the negative. The positions of the coördinate lines with reference to the stars in the diagram are only roughly approximate. The enlargement as compared with the original negative is about five diameters.

YERKES OBSERVATORY,
September 26, 1901.

NOTES ON VARIABLE STARS.

By J. A. PARKHURST.

THE forthcoming publication of a new catalogue of variable stars by the commission appointed by the *Astronomische Gesellschaft*, is the occasion of the following preliminary report of observations made with a 6½-inch reflector and the 12- and 40-inch refractors of the Yerkes Observatory. The final reduction is reserved till the completion of the work, now in progress, of finding the photometric magnitudes of the comparison stars. The approximate magnitudes here assigned are based on the assumption for the limits of the apertures used, of 12.8 magnitude for the 6½-inch; 14.0 magnitude for the 12-inch, and 17.0 magnitude for the 40-inch. The notation of Dr. Chandler is followed; for stars not in the *Third Catalogue* the provisional number, in parenthesis, being one-tenth the Right Ascension for 1900, expressed in seconds of time. The dates of maxima and minima are only roughly indicated, the more definite determination being reserved for the final reduction. This report is a continuation of those in the *Astronomical Journal*, **21**, 11, and the ASTROPHYSICAL JOURNAL, **12**, 52.

103. *T ANDROMEDAE.*

Minima were passed late in December, 1899, and early in October, 1900. The magnitude at minimum was about at the limit of the 6½-inch, but an examination of the field with the 40-inch showed no stars liable to be mistaken for the variable when faint, those nearer than 4′ being of the fourteenth magnitude or fainter. The variable was not far from maxima in May, 1900, and February, 1901. These data result from twenty-eight observations.

243. *U CASSIOPEIAE.*

This star faded from the tenth to below the fourteenth magnitude between 1898, June 27 and August 17; also from the eleventh to the fourteenth magnitude between 1900, January 21 and February 22; but the observations, nine in number, do not suffice to fix the minimum in either case.

267. *V ANDROMEDAE.*

After the minimum reported in this JOURNAL, **12,** 52, the variable passed a maximum at the ninth magnitude in May, 1900, and a minimum at the fourteenth magnitude in October of the same year.

294. *W CASSIOPEIAE.*

A maximum at 8½ magnitude was passed in December, 1899, and a minimum about the twelfth magnitude, in June, 1900.

466. *U PISCIUM.*

This star was twelfth magnitude, 1900, January 21, and had faded to less than fourteenth magnitude when last seen, February 22. There were no stars brighter than the fourteenth magnitude noticed with the 40-inch, within less than 2′ of the variable.

659. *X CASSIOPEIAE.*

This intensely red star (spectral type III, b; Dunér) remained with slight fluctuations near the twelfth magnitude during 1899, and passed a poorly defined maximum about the tenth magnitude in February or March, 1900. As there are forty well-distributed observations during this period the presence of any considerable minor maxima or minima is rendered very doubtful.

678. *U PERSEI.*

Minima were passed, a little fainter than the twelfth magnitude, late in December, 1899, and early in November, 1900; also a seventh magnitude maximum in May, 1900.

(787)—*ANDROMEDAE.*

The discovery by Anderson was announced in *A. N.*, **147,** 175. The position, found by micrometer comparisons with *Bonn A. G. Cat.*, 1887 and 1939, is—

R. A. $2^{h}\ 8^{m}\ 24^{s}.7$, Decl. $+43^{\circ}\ 37'\ 46''$ (1855)
11 14.1 50 26 (1900)

A chart of the neighboring stars brighter than the thirteenth magnitude will be found in *Popular Astronomy*, **8,** 162.

My first observation was 1899, February 6, when the variable was found at 10.0 magnitude. It faded steadily, passing below the limit of the 6½-inch in April, and remaining invisible in that instrument till August 30, when it was found at 12.0 magnitude. It then increased in light and passed a maximum at 7.0 magnitude about the first of December, 1899. The following minimum, at 14.0 magnitude, the last of July, 1900, was observed with the 12- and 40-inch telescopes.

(1922)—*AURIGAE.*

Discovered by Madam Ceraski (see *A. N.*, **147,** 15). The position found by micrometer comparisons with *DM.* + 36° 1141 (place from the Lund Zones) is—

R. A. $5^h\ 17^m\ 6^s.0$, Decl. + 36° 46′ 11″ (1855)
20 8.6 48 53 (1900)

After the minimum reported in this JOURNAL, **12,** 54, it was found at the tenth magnitude in August, 1900, and at 11.5 magnitude in February, 1901. The identification in its faint stages presents no difficulty, a wide pair of fifteenth magnitude stars 1′ south aiding materially.

2013. *U AURIGAE.*

When first seen, 1899, January 8, this star was 10.5 magnitude. It faded steadily and passed below the reach of the 6½-inch the last of March, and could not be seen when looked for in April and May. It had risen to 8¼ magnitude in November, and passed a maximum about eighth magnitude early in December, 1899, and had fallen to the eleventh magnitude in April, 1900. There is a fourteenth magnitude star 20″ south following, which will aid in identifying it in its faint stage.

2376. *S LYNCIS.*

This star passed a maximum a little brighter than the ninth magnitude in May, 1900.

2742. *S GEMINORUM.*

The observations of 1900 began too late to fix the minimum, but the star was found between the twelfth and thirteenth magnitude in January and February and had risen to tenth magnitude April 17.

2404. *X GEMINORUM.*

A maximum at the eighth magnitude was passed in December, 1899, and a minimum at the twelfth magnitude in April, 1900. It was little, if any, past a minimum early in February, 1901.

4471. *T CANUM VENATICORUM.*

This star passed a maximum, rather brighter than the ninth magnitude in September, 1899, and a twelfth magnitude minimum in February, 1900.

4315. *R COMAE.*

After passing a ninth magnitude maximum about 1900, July 25, and fading half a magnitude, the star again brightened, and when last seen, August 18, it was as bright as at any time in July. The strong twilight rendered these estimates of small weight.

5070. *Z VIRGINIS.*

This star was again brightening during the spring of 1901, being thirteenth magnitude May 18, and twelfth magnitude June 3.

5798. *RU HERCULIS.*

The minimum of 1900 was followed with the 12- and 40-inch telescopes. The star was fainter than the thirteenth magnitude from the last of February to the first of May, the minimum, a little brighter than the fourteenth magnitude, being passed about the first of April.

5830. *R SCORPII.*

A maximum about 10.5 magnitude, was passed in August, 1900. The star was fainter than the thirteenth magnitude 1901, June 7, and fainter than the fifteenth magnitude July 8.

5831. *S SCORPII.*

This star passed a tenth magnitude maximum in May, 1900, and was found at the thirteenth magnitude and fading in June, 1901.

5601. *S URSAE MINORIS.*

This star passed an eighth magnitude maximum the latter part of June, 1900, and was again near minimum in November and December of the same year.

6100. *RV HERCULIS.*

A faint maximum, about tenth magnitude, was passed in June, 1900, and a sixteenth magnitude minimum in September of that year. It was 13.5 magnitude 1901, May 18, and 11.5 June 3.

6449. *T DRACONIS.*

After the maximum of 1899, August 15, this star faded slowly and remained fainter than its 10.5 magnitude companion from the first of December, 1899, to the last of June, 1900. It then rose to 8.5 magnitude by the middle of September, and remained at that brightness, with some fluctuations, the rest of the year.

(6452)—*HERCULIS.*

The discovery by Anderson is noted in *A. N.*, **150,** 325. The position, based on micrometer comparisons with the neighboring *Berlin A. G. Catalogue* stars, is

R. A. $17^h\ 53^m\ 27^s.7$, Decl. + 19° 29′ 41″ (1855)
55 24.7 29 20 (1900)

It passed eighth magnitude maxima about the first of March and the last of October, 1900, and a minimum between 13.5 and fourteenth magnitude, the latter part of June of the same year.

(6458)—*DRACONIS.*

The notice of discovery by Anderson is given in *A. N.*, **151,** 307. The position from micrometer comparisons with the neighboring *Cambridge A. G. Catalogue* stars, was found to be

R. A. $17^h\ 55^m\ 24.4^s$, Decl. + 54° 53′ 01″ (1855)
56 17.2 52 45 (1900)

After the rise noted in this JOURNAL, **12,** 54, the star passed a maximum about 9½ magnitude in July, 1900, and had fallen below the limit of the 6½-inch the last of October of that year.

6549. *W LYRAE.*

Maxima were found, about 8.0 magnitude in December, 1899, and June, 1900; with a twelfth magnitude minimum in March, 1900. It had risen nearly to maximum by the last of December, 1900.

6871. *V LYRAE.*

The first minimum completely observed was that of 1900. The star was 12.0 magnitude January 1, and fell steadily to a minimum about 15.5 magnitude the latter part of June, and rose to a 9.5 magnitude maximum about November 1. By the last of December it had again fallen to 11.5 magnitude. It was below the thirteenth magnitude for nearly six months, from the last of March till September. By the aid of the light curve thus obtained the minimum of the year 1899 can be located near the first of June, since the variable was below the limit of the 6½-inch from the last of February till August 9. The maximum of this year was passed in October at nearly the same brightness as that of 1900. The resulting period of a little less than thirteen months is confirmed by one observation, 1901, July 9, when the variable was found near minimum.

6894. *S LYRAE.*

The minimum reported in this JOURNAL, **12**, 53, was followed by a 9.5 magnitude maximum in September, 1900. The variable is preceded by two fifteenth to sixteenth magnitude stars, the three forming a line about ½′ long.

6899. *U DRACONIS.*

This variable passed a 13.5 magnitude minimum early in March, 1900, at a ninth magnitude maximum late in July of the same year.

7085. *RT CYGNI.*

A twelfth magnitude minimum was passed in December, 1899, a 7.5 magnitude maximum in March, 1900, an eleventh magnitude minimum in June and a seventh magnitude maximum in September, 1900.

7220. *S CYGNI.*

The minima of this star prove to be extremely faint. It was at the limit of the 40-inch in July, 1900, had brightened perceptibly in August, and then rose steadily to 12.5 magnitude by the middle of November. The observations began too late to fix the date of minimum, but it was probably late in July.

(7248)—*AQUILAE.*

Anderson's discovery of this variable is reported in *A. N.*, **147,** 269. Its position from micrometer comparisons with + 12° 4255 (*Bonn* VI) is

R. A. 20^{h} 5^{m} $56^{s}.3$. Decl. + 12° 33′ 46″ (1855)
8 3.1 41 41 (1900)

Near its minimum in 1899 it was invisible in the 6½-inch from August 9 to November 22. It passed a maximum too near the Sun for observation, during the interval between 1900, January 2 and March 2; then faded from eleventh magnitude in March to a 14½ magnitude minimum early in June; then rose to an 8½ magnitude maximum in October, and had fallen to the twelfth magnitude at the last comparison, 1900, December 19.

There is a 12½ magnitude star 32″ north of the variable.

(7258)—*CYGNI.*

The discovery by Anderson is noted in *A. N.*, **150,** 325. The position from micrometer comparisons is:

R. A. 20^{h} 9^{m} $44^{s}.7$, Decl. + 30° 37′ 56″ (1855)
11 32.9, 46 3 (1900)

After the minimum reported in this JOURNAL, **12,** 54, the star rose steadily to a maximum about 9¼ magnitude in October, 1900, and had fallen to the twelfth magnitude by the last of December.

7379. *ST CYGNI.*

After the maximum of 1899, May 30, the star fell steadily and passed below the limit of the 6½-inch the last of September of that year. It was next glimpsed with the 6½-inch 1899, December 5, and rose to a 9½ magnitude maximum about 1900, May 1. The following minimum, observed with the 12- and the 40-inch telescopes, was not sharply defined, the star remaining near 13.5 magnitude during August, September, and October of 1900, and rising to 10½ magnitude by the last of December. As the positions of six of the neighboring stars were measured with the 40-inch and the field made quite familiar, it does not seem that misidentification was to be feared.

7458. *V DELPHINI.*

In continuation of the report in this JOURNAL, **12,** 54, this star remained at or below the limit of the 40-inch during the interval July–October, 1900. There is a sixteenth magnitude star 1′ south and a trifle following the variable.

7492. *RZ CYGNI.*

This star passed a twelfth magnitude minimum in January, 1900, and fluctuated between that brightness and 10.5 magnitude for the remainder of the year.

7502. *X DELPHINI.*

This star remains for several weeks at minimum below the limit of the 6½-inch. It passed a maximum, a little brighter than the ninth magnitude, in the latter part of June, 1899, and had faded to the limit of the 6½-inch at the last comparison of the season, November 27. It was again near maximum 1900, May 1, and faded gradually till the last of October, when it was between 13½ and fourteenth magnitude.

(7579)—*CEPHEI.*

The discovery by Madame Ceraski is reported in *A. N.*, **147,** 142. The position from micrometer measures is

R. A. $21^{h}\ 6^{m}\ 39^{s}.2$, Decl. $+82^{\circ}\ 28'\ 58''$ (1855)
$3\ \ 38.5$ $39\ \ 50$ (1900)

The variable remained below the limit of the 40-inch from 1900, May 29, to October 16. On October 25 it was about sixteenth magnitude, and 1901, January 24, it had risen to fourteenth magnitude, while May 16 it was near maximum, about 10½ magnitude. By the kindness of the then Director Keeler a photograph of the field was taken, with two hours' exposure, with the Crossley telescope of the Lick Observatory, 1900, July 24, which showed the variable about half a magnitude fainter (photographically) than the visual limit of the 40-inch.

(7594)—*AQUARII.*

This is *S. DM.* −4° 5381. Its discovery by Barnard is given in this JOURNAL, **19,** 193. Its place for 1855 is

R. A. $21^h\ 3^m\ 22^s.7$, Decl. $-4°\ 37'.4$

It passed below the limit of the 6½-inch the latter part of October, 1899, and was again past maximum and fading from tenth to eleventh magnitude in April and May, 1900. It was near minimum, rather fainter than fourteenth magnitude, 1900, June 28, and rising steadily passed a tenth magnitude maximum in October of that year.

(7656)—*PEGASI.*

The discovery of this variable by Anderson is recorded in *A. N.*, **147**, 287. Its position from micrometer comparisons with neighboring catalogue stars is

$21^h\ 14^m\ 7^s.5$, Decl. $+13°\ 50'\ 17''$ (1855)
16 14.9 14 1 36 (1900)

Minima were observed, about thirteenth magnitude, late in December, 1899, and in July, 1900. Maxima at 8½ magnitude were passed early in March and in October, 1900.

7896. *V PEGASI.*

After the maximum of July, 1899, the variable faded slowly and passed below the limit of the 6½-inch the last of November. It was next seen 1900, May 1, at 9.0 magnitude and passed an eighth magnitude maximum the latter part of May, then faded slowly to fourteenth magnitude when last observed, 1900, October 24.

8324. *V CASSIOPEIAE.*

Minima at about 12.5 magnitude were passed in December, 1899, and early in August, 1900. Maxima at 7½ magnitude were found in March and early in November, 1900.

(8517)—*CASSIOPEIAE.*

R. A. $23^h\ 39^m\ 39^s.9$, Decl. $+56°\ 1'\ 34''$ (1900)

The discovery by Anderson and measures of position by Hartwig are given in *A. N.*, **148**, 79, and **149**, 6, respectively. The variable was 10½ magnitude and fading early in January, 1899. It passed below the limit of the 6½-inch early in April and remained invisible in that instrument the rest of the year. It was found between the fourteenth and fifteenth magnitude with the 40-inch in January, 1900, rose to a 9½ magnitude maximum in March, and fell to 12.5 magnitude the last of August, 1900.

(8629)—*CASSIOPEIAE.*

The discovery by Mrs. Fleming, and the position for 1900,

R. A. $23^h\ 55^m\ 53^s$, Decl. + 54° 52.3,

are given in *Harvard College Observatory Circular* No. 24.

After the maximum of 1899, April 8, the variable faded slowly, passing below the limit of the 6½-inch in September and remaining invisible in that instrument for the rest of the year. A minimum at about 13.5 magnitude was observed with the 12- and 40-inch telescopes in January, 1900, followed by a 9½ magnitude maximum in June. It had passed below the twelfth magnitude in November, 1900.

YERKES OBSERVATORY,
September 6, 1901.

THE WAVE-NUMBER SYSTEM OF RHODIUM.

By C. P. SNYDER.

PURSUANT to the advice of the late Professor Rowland the writer presents the results of his investigations on the wave-number relations in the arc-spectrum of rhodium; which results are embodied in the "Rhodium Table," and description following. The table contains 476 wave-numbers out of a total of 1471; that is, it contains about 32 per cent. of the total number.

DESCRIPTION OF THE RHODIUM TABLE.

In the columns headed A, B, C–S, and rows numbered 1, 2, 3–52, are given certain wave-numbers of the arc-spectrum of rhodium as given by Kayser. Between the columns A, B; B, C; etc., are given the differences between successive wave numbers in the same line; and, between the rows 1, 2; 2, 3; etc., are given the differences between successive wave-numbers in the same column. It will be noticed that for any pair of columns all the differences obtained by subtracting corresponding wave-numbers are the same; and, of course, the same is true for any pair of rows. By corresponding wave-numbers in the columns I mean those found upon the same line in the table.

It will also be noticed that there are what may be called complementary columns, as I and M, G and H, etc., in which the gaps of one correspond to the wave-numbers found in the other. For example, in H there is a wave-number on line 3, but none on 4 or 5; in S there are wave-numbers on lines 4 and 5, but none on 3, etc. There are also groups of rows in which a series of gaps is repeated, *e. g.*, for each of the rows 5, 7, 11, 15, 22, 36, 43 we find gaps in the columns H, I, J, N, O.

It may also be readily seen that the wave-numbers of "reversed" spectral lines (indicated by *r*) are to be found only in the "final" columns of the table. This relation seems to be connected with that which determines the distinction between "rows" and "columns" in the table, viz., the number of rows should considerably exceed the number of columns.

[In addition to the foregoing relations, the writer thinks he has found, in the arc-spectrum of palladium (as given by Kayser), a "sub-system" which has the same series of wave-number differences as that of the "principal system" for the given element; except that the order of differences is reversed; thus, where the principal system has the column of wave-numbers A, $A+d_1$, $A+d_2$, etc., the sub-system has a column of wave-numbers B, $B-d_1$, $B-d_2$, etc; this relation may be connected with the occurrence, in the given spectrum, of two sets of lines, shaded in opposite directions.]

In addition to the rhodium table the writer has found a quite extensive system for ruthenium, containing several hundred wave-numbers; also systems for iridium, nickel, platinum, palladium, and osmium.

NOTE.— Rows 23½ and 44½ were omitted by error, and are not included in the computations of mean differences of wave-number between successive rows and columns.

As subsequent investigation will probably alter the positions assigned to some of the wave-numbers, the writer has spent little time in estimating the most probable values of the aforementioned mean differences. A much more accurate estimate of these mean differences might be obtained by including Professor Rowland's values for the arc-spectrum of the element.

		S		Mean Differences	
54446	152987	10r	2707433		1
46731			146718	146727	
1177	152974	8r	2854151		2
31684			(88834)	31698	
32861					3
0666)				57107	
		8r	2942985		4
			43534	43551	
33527	152992	1	2986519		5
43543)			(123563)	53095	
					6
				70438	
57070	153012	4	3110082		7
37290)			(51189)		
					8
				32780	
4360					9
3911				13910	
8271	153000	1	3161271		10
39018			39031	39023	
47289	153013	6	3200302		11
4240			(103976)	4231	
1529					12
9702				19699	
1231					13
30072)				3409	
					14
				76647	
1303	152975	2	3304278		15
0235)			(228996)	82315	
					16
				7929	
1538					17
8608)				138745	
		2	3533274		18
			(145367)	7034	
					19
				26534	
					20
				46310	
0146					21
5256)				63474	
		3	3078641		22
			(122526)	19775	
5402					23
2771				102759	
8173	152994	2	3801167		24
1405)			(227160)	2537	
					25
				17278	
					26
				45786	
					27
				4925	
					28
				88	

SPECTROSCOPIC STUDIES.[1] I.

By EDUARD HASCHEK.

I. COMPUTATION OF THE PRESSURE IN THE SPARK FROM THE DISPLACEMENTS OF THE LINES.

THE effect of pressure upon the wave-length of lines in the electric arc has been investigated for a large number of elements by W. J. Humphreys and J. F. Mohler[2] in a series of researches undertaken, in part individually, and in part in collaboration. The principal results of their work are the following: With increase of pressure in the gas surrounding the arc the individual lines in the arc spectrum become displaced toward the red, with the increase of wave-length proportional to the pressure of the gas. The displacement of the lines varies with the element, and is a periodic function of its atomic weight. Within a single spectrum, however, the displacements also vary, and are proportional to the wave-length of the line, so that for a definite number of lines referred to the same wave-length they are constant. If one compares the lines of different series of the same element, then the relative displacements are found to be in the ratio 1:2:4.

In view of the above-mentioned results of Humphreys and Mohler, it is natural to infer the existence of pressure in all cases of incandescent gases in whose spectra displacements of the lines are observed, and so long as we know of no other causes which might occasion a variation in wave-length it is permissible to compute the amount of the pressure from these displacements. Both of these conclusions have been drawn. Thus F. Exner and E. Haschek,[3] in the course of their measures of the ultra-violet spectra of the elements, observed considerable displacements of the spark lines analogous to those in the arc, and explained them on the ground of pressure in the spark, deriving the amount of this pressure from the absolute magnitude of the displacements. The pressure in the path of the electric discharge was then observed directly by E. Haschek and H. Mache,[1] and its dependence upon the experimental conditions quantitatively determined. The values thus obtained are considerably larger than those computed from the displacements, and the difference is not capable of explanation on the simple ground of inaccuracies of observation. Finally J. F. Mohler,[2] also from the displacements of the lines, determined the pressure in the spark of an induction coil, and found small values corresponding to the slight displacements. It is noteworthy, however, that the ratio between the pressure found directly and the computed pressure is nearly the same in the case of the induction coil as in that of the transformer which E. Haschek and H. Mache employed chiefly, and lies between 2 and 2.5.

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[1] *Sitzungsberichte der Kais. Akad. der Wiss. in Wien.* Math.-naturwiss. Classe. 110, Abth. II, March, 1901.

[2] ASTROPHYSICAL JOURNAL, 1896, 1897.

[3] *Sitzungsberichte der Kais. Akad. der Wiss. in Wien*, 1897 ff.

These discrepancies between the values of measurement and those of the indirect determination of the pressure in the spark cause one to doubt the admissibility of directly applying to the spark the results of Humphreys and Mohler. It will be shown in the following paper that other laws govern the displacements of spark lines from those of the arc, and hence that a derivation of the spark pressure from the displacement of the lines is not admissible. For this we need to know the displacements of a larger number of spark lines, for which the corresponding quantities in the arc spectrum are also given in Humphreys' comprehensive research. It is clearly not allowable to compute the pressure in the spark from the displacement of lines which have not been investigated in the arc. In the case of most elements the relation of the lines to the series is not known, and so the possibility is excluded of applying the last of the above-mentioned results of Humphreys.

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[1] *Sitzungsberichte*, etc., 1898.

[2] ASTROPHYSICAL JOURNAL, **10**, 202, October, 1899.

If it is allowable to infer a pressure in the spark from displacement of the lines, it is clear that the displacement for all the lines must furnish the same value for the pressure, if no other influences are at work. If such influences are present, however, the values will, in general, prove different, and cases may be imagined in which certain external conditions will influence many lines or groups of lines differently from others. Consequently it will not necessarily follow that the empirical classification of lines in series will hold good in all cases.

Our first problem, then, will be to determine the displacements for a considerable number of lines of different elements, all of which have been obtained under nearly identical external conditions, and from these displacements to compute the pressure in the spark. After this we shall have to seek for other causes which have to do with the displacements of lines, and to attempt to determine the laws which govern the variations in wave-length.

The material for the first part of our investigation is furnished us by the measures of Professors F. Exner and E. Haschek upon the ultra-violet spark spectra of the elements, all of which have been carried out under the same conditions and with the same degree of accuracy. The values which are employed here are taken in part from publications and in part from a new determination of the spectra, which is soon to be issued. In order to avoid a great number of tables, we shall note here only those lines which show a plain displacement, taking as a lower limit for this the value of 0.03 t. m. The measures of the spark spectra are on the average accurate to 0.015 t. m., and consequently deviations up to 0.02 t. m. will be regarded as errors of observation. Larger errors will occur but very seldom.

To determine the displacements of the spark lines we apply for comparison the values in the arc spectrum. Where possible, only the results of Rowland, in part for the arc and in part for the solar spectrum, have been employed, but since the values of the lines in the two cases do not completely agree, the figures have been rounded off to two decimal places.

The first three columns of the following tables need no explanation. In the fourth column $\Delta(\lambda \text{ spark} - \lambda \text{ arc})$ denotes the displacement of the spark line, and in the fifth, $\Delta\lambda$ the displacement of the arc line[1] for a pressure of one atmosphere in the surrounding gas. The ratio $\frac{\Delta(\lambda \text{ spark} - \lambda \text{ arc})}{\Delta\lambda}$ gives the pressure in the spark, which is given in atmospheres in the sixth column and denoted by P.

Element	λ (Arc)	λ (Spark)	Δ (Spark – Arc)	Δ λ	P
Al	3092.82	3092.89	0.07	0.0049	14
	3944.16	3944.22	0.06	0.0043	14
	3961.68	3961.74	0.06	0.0047	13
Ge	3269.63	3269.70	0.07	0.0026	27
	4226.72	4226.76	0.04	0.0013	9
n	3302.72	3302.75	0.03	0.0031	9
	3345.16	3345.20	0.04	0.0029	14
	3382.46	3282.49	0.03	0.0030	10
	4680.32	4680.43	0.11	0.0064	17
	4722.34	4722.50	0.16	0.0057	28
Ca	3159.00	3159.11	0.11	0.0052	21
	3179.45	3179.60	0.15	0.0046	33
Si	2516.21	2516.26	0.05	0.0014	35
	2881.70	2881.73	0.03	0.0025	12
	3905.66	3905.71	0.05	0.0035	14
Zr	3958.36	3958.39	0.03	0.0014	21
	3999.12	3999.18	0.06	0.0027	22
	4029.80	4029.88	0.08	0.0026	31
Cr	3886.93	3886.97	0.04	0.0022	18
	3919.31	3919.36	0.05	0.0018	28
	3963.83	3963.88	0.05	0.0026	19
	3984.06	3984.09	0.03	0.0032	9
	4280.56	4280.59	0.03	0.0024	13
i	3200.03	3200.07	0.04	0.0026	15
	3234.64	3234.72	0.08	0.0017	47
	3242.13	3242.19	0.06	0.0014	43
	3254.31	3254.41	0.10	0.0020	50
	3326.91	3326.99	0.08	0.0016	50
	3341.97	3342.00	0.03	0.0018	17
	3349.04	3349.14	0.10	0.0014	71
	3361.33	3361.40	0.07	0.0011	64
	3380.40	3380.45	0.05	0.0019	26
	3900.68	3900.81	0.13	0.0020	65
	3904.93	3904.98	0.05	0.0018	28
	3913.61	3913.72	0.11	0.0018	61
	3924.67	3924.72	0.05	0.0015	33
	3958.36	3958.39	0.03	0.0018	17
	3981.92	3981.96	0.04	0.0020	20
	3989.91	3989.95	0.04	0.0015	27
	3998.79	3998.86	0.07	0.0016	44

Computed from all the individual observations.

Element	γ (Arc)	λ (Spark)	Δ (Spark – Arc)	Δ λ	P
	4009.08	4009.11	0.03	0.0015	20
Ce	3895.22	3895.29	0.07	0.0031	23
	3896.92	3896.98	0.06	0.0021	29
	3921.86	3921.90	0.04	0.0034	12
La	3929.36	3929.40	0.04	0.0026	15
	4043.05	4043.18	0.13	0 0036	36
	4086.86	4086.90	0.04	0.0026	15
Sc	4314.25	4314.32	0.07	0.0025	28
	4320.91	4321.01	0.10	0.0022	45
Y	4309.78	4309.81	0.03	0.0011	27
	4422.76	4422.80	0.04	0.0020	20
Cs	4555.44	4555.80	0.36	0.0201	18
	4593.34	4593.50	0.16	0.0133	12
Va[1]	3922.56	3922.63	0.07	0.0016	44
	3925.35	3925.40	0.05	0.0017	29
	3934.11	3934.19	0.08	0.0006	133
	3990.71	3990.80	0.09	0.0028	32
	3992.97	3993.00	0.03	0.0019	16
	4051.20	4051.25	0.05	0.0020	25
	4051.49	4051.60	0.11	0.0024	46
	4092.82	4092.92	0.10	0.0013	77
	4105.32	4105.40	0.08	0.0029	28
	4123.54	4123.74	0.20	0.0023	87
	4128.25	4128.30	0.05	0.0024	21
	4132.10	4132.21	0.11	0.0016	69
	4134.60	4134.72	0.12	0.0028	43

An examination of the above tables shows at once that only in extremely few cases is the computed pressure approximately constant for all the lines. Yet this really means but little. In the tables only lines with a considerable displacement have been included. All those for which Δ (λ spark–λ arc) =0 furnish a zero pressure. Indeed, it happens very rarely that the wave-lengths in the spark spectrum are smaller than those in the arc.[2] The displacement and hence the pressure is therefore negative. In general the computed pressures differ so widely from one another that one cannot but conclude that other causes are instrumental in determining the displacement of the lines. The differences are not capable of explanation on the ground of inaccuracies of observation, although it must be admitted that the absolute values of the displacements of the lines in the spark spectrum do not possess the accuracy of those of the arc. Still, errors of observation can influence the results seriously only in cases of small displacements.

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[1] The results of H. A. Rowland and C. N. Harrison for the arc spectrum (ASTROPHYSICAL JOURNAL, Vol. VII, No. 4, April, 1898) are clearly too low, as is seen from the wave-lengths of the *Ca* lines, which were allowed to remain in the spectrum and were measured with them. The difference is not a constant one, and hence is difficult of correction. The above values were taken from the solar spectrum.

[2] Compare F. EXNER and E. HASCHEK, "Über die ultravioletten Funkenspectra der Elemente," Section XI, *Sitzungsberichte*, etc., 107, 1898.

The values given indicate still more. According to the results of Humphreys, lines admit of arrangement according to the displacements which they suffer. Lines with an equal displacement can be classed in groups which belong together, and it then becomes evident that exactly the same lines which have been arranged in series by Kayser and Runge are indicated by their relatively equal displacements. If the results of Humphreys held true generally this relation would have to exist for the spark as well. Comparison of the observed displacements shows, however, that many of the lines for which Humphreys found large displacements alter their wave-lengths but little in the spark, and conversely. This behavior is especially marked in the case of *Ti* and *Va*. The lines λ4051.2 and λ4051.5 (*Va*) show nearly equal displacements in the arc, while in the spark their displacements are in the ratio 1 : 2. On the other hand the lines λ4132.1 and λ4134.6 (*Va*), which have nearly equal displacements in the spark, exhibit in the arc a marked difference from one another in this respect. Similar cases might be mentioned. The behavior of *Ca* is especially striking. Humphreys observed considerable displacements in a large number of the lines of this element. In the spark, however, only two appear to be displaced, all the others showing no shift, although anything of the sort would have been detected readily.

If we summarize the results so far found we have the following:

1. There occur in the spark spectrum considerable displacements of lines in the direction of an increase of wave-length, which are analogous to those observed by Humphreys and Mohler in the arc under pressure, but which attain higher values.

2. If these displacements of the lines are assumed to be dependent solely upon the pressure existent in the spark, this pressure

being experimentally determined, and if the pressure in the spark is computed from the displacement in the spark and in the arc, then values will be found for the same element which vary greatly according to the line chosen.

3. Lines with equal displacements in the arc show very different displacements in the spark, and conversely. The rule that the lines of the series of Kayser and Runge show relatively equal displacements is not confirmed for the spark.

II. CONCERNING THE DEPENDENCE OF THE WAVE-LENGTH UPON THE DENSITY OF THE LUMINOUS VAPOR.

We have hitherto always regarded the shift of the lines as dependent upon pressure in the path of the spark and have considered the spark pressure the sole cause. Previous investigations show, however, that still other causes can be found. Of course it is difficult to obtain always the same conditions for an experiment. In fact the investigation conducted by Haschek and Mache,[1] "On the Pressure in the Spark," has shown that the pressure in the spark depends to a great extent upon the arrangement of the experiment. We beg to repeat briefly here the results of this investigation.

A high potential transformer was used, the primary of which was fed with an alternating current of 100 volts. In the secondary circuit measured capacities could be introduced in parallel with the spark gap. It was found that the pressure in the spark depends upon the kind of electrodes used, the pressure and nature of the surrounding gas, and the amount of capacity employed, but not upon the length of the spark. The pressures obtained by employing the high potential transformer are quite considerable. If an induction coil be used the difference of pressure between the spark and its enveloping gas is substantially smaller, as was determined qualitatively from the measurements of Mohler.[2] In general it may be said that the pressure becomes greater as the amount of electric energy which passes between the terminals in a single spark is increased.

[1] E. HASCHEK and H. MACHE, ASTROPHYSICAL JOURNAL, 9, 347, 1899.

[2] J. F. MOHLER, ASTROPHYSICAL JOURNAL, 10, 202, 1899.

An explanation of the origin of spark pressure may be found in the investigation of H. Schuster,[1] who observes that the small particles of the metallic vapor dislodged from the electrodes move with great velocity, which diminishes sharply with increasing distance from the electrodes. From this it follows that the particles crowd together toward the middle of the path of the spark, so that the pressure increases with the distance from the electrode. A conception of how the pressure affects the wave-length of the emitted light may be obtained by considering that upon a sufficiently close approach the particles must exert mutual forces upon each other. These light producing particles will then no longer vibrate freely, but under the influence of a dampening, which causes an increase of wave-length.

If this reasoning be correct, then, in all cases in which we increase the number of light-producing particles in unit volume, and, consequently, the density of the luminous vapor, there must result an increase of wave-length, and hence a displacement of the lines toward the red. Here those conditions which affect the pressure in the path of the discharge must of course be kept as constant as is feasible, particularly, therefore, the current strength and capacity in the secondary circuit.

Experiments on the influence of vapor density on the wave-length of the lines were made upon potassium, which shows a considerable displacement. The process was as follows: Carbon terminals were moistened with variously concentrated solutions of caustic potash in water — 100 cu. cm of the latter and 0.2, 2, 20, and 200 grams of the former. To render the carbons porous, they were warmed a few seconds in the arc. In every case the amount of solution employed was 0.75 cu. cm, so that the amounts of potassium used bore the ratio, 1 : 10 : 100 : 1000. It is permissible to assume that the numbers of the potassium particles present in the spark gap were likewise in the same ratio. The spark and arc spectra of carbons prepared in this manner were obtained photographically with a Rowland concave grating of 15 feet radius and 20,000 lines to the inch. The carbons were renewed for every experiment; the times of exposure employed were 5 and 150 seconds for arc and spark respectively. The spark was produced by a high potential transformer, supplied by a primary current of 12 amperes and 100 volts, which was transformed up to about 10,000 volts. In the secondary circuit, in parallel with the spark gap, was inserted a condenser battery of 625 meters capacity. The arc spectra were produced by a direct current of 110 volts and about 8 amperes. For all the experiments the external conditions remained the same. As measuring standards in all cases there were used the lines of the arc spectrum of iron, obtained photographically by a three-second exposure. For measurement the spectra were enlarged thirtyfold by projection and the position of the lines read off a scale. Relative to the method of measurement itself, the reader is referred to the work of F. Exner and E. Haschek.[1]

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[1] *Nature*, 57, 1899; 59, 1899; A. SCHUSTER and G. HEMSALECH, *Phil. Trans.*, 193, A. 1899.

The following tables give the results of the measurements made upon the two violet potassium lines λ4044 and λ4047. It may be stated that every measurement given represents the mean of at least ten readings differing but little among themselves, and that the wave-lengths given are accurate to at least 0.002 tenth-meters for small concentration and 0.003 tenth-meters for large concentration.

A. UNREVERSED LINES.

Concentration	Arc	Spark	Arc	Spark
0.2	4044.313	4044.300	4047.374	4047.360
2.0	4044.332	4044.320	4047.387	4047.382
20.0	....	4044.382	....	4047.450
200.0	....	....	....	4047.655

B. REVERSED LINES.

20.0	4044.310	....	4047.365	....
200.0 (*a*)	4044.392	4044.321	4047.392	4047.418
200.0 (*b*)	4044.392	4044.360	4047.392	....

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[1] F. EXNER and E. HASCHEK, *Sitzungsberichte*, **104**, Sec. II *a* and following.

As a consequence of an unequal moistening of the electrodes there appears in the spark spectrum at highest concentration an asymmetry between the two ends of the lines. To increase the intensity of the light there was inserted between spark and slit a quartz condensing lens which gave approximately parallel light. The ends of the lines in the spectrum always correspond to the parts of the spark which lie near the electrodes, while the middle of the line answers to the middle of the spark. If, then, the spark show non-uniformity in its direction, this, to a certain degree, will be pictured in the lines. In the case in hand, by reason of the dripping of the solution from the upper to the lower electrode, the amount of potassium entering, and therefore the amount present in the path of the spark was different at the two ends — at the upper less, at the lower greater. The result is that at the end corresponding to the less density of luminous potassium vapor only the line λ 4044 appears reversed, while at the other both appear so. In the arc as also in the spark the reversal was not accurately symmetrical; in the latter case, morever, the red component was regularly stronger than the violet.

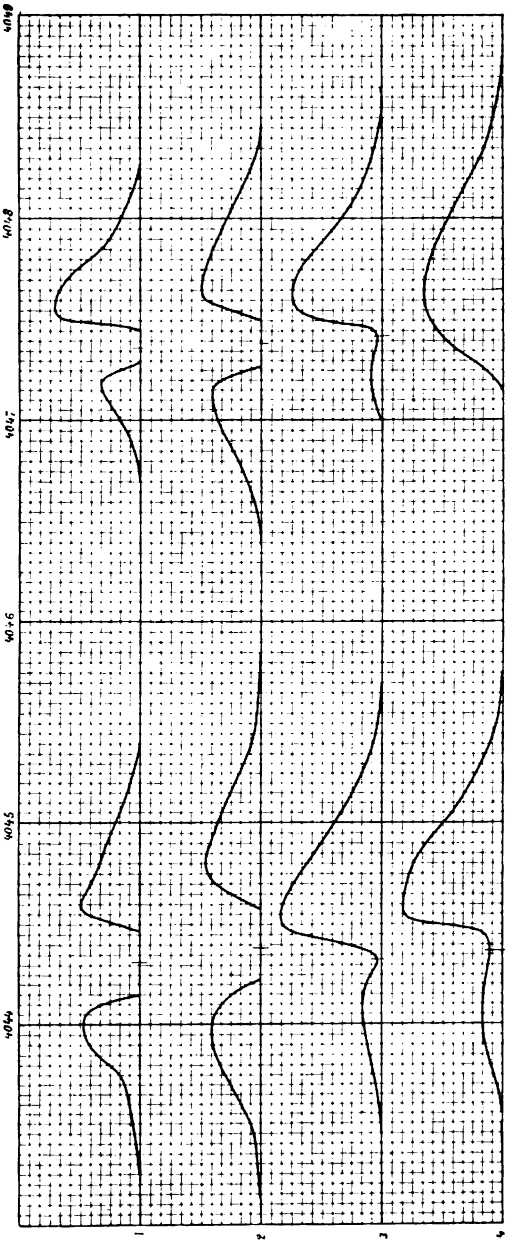
As to the wave-lengths themselves we draw from the table the remarkable result that at smallest concentration — that of 0.2 gram of caustic potash to 100 cu. cm of water — the wave-lengths of lines in the spark are smaller than those in the arc. Judging by Humphrey's results we must then assume that in this case there is about 1.3 atmospheres greater pressure in the arc than in the spark. Again in case of the next higher concentration the wave-lengths of the arc lines are greater than those of the spark lines, although the difference in this case is smaller. Considering the variation of wave-length with density, the table shows a constant increase of the same with increasing concentration. This holds equally for the lines and their reversals. The latter are also displaced. It appears that the wave-length of the reversal is smaller at the critical density than at the smallest density of potassium vapor employed, and further that this density lies higher for the spark than for the arc.

By critical density is meant that density at which the reversal of the line just begins.

Suspicion seems to be justified that the wave-length of the reversal at the critical density agrees perfectly with the least possible wave-length of the line.

The behavior of the lines with the highest concentration in the spark is again of especial interest. At one end (*a*) both lines appear reversed in consequence of the above-mentioned inequality in the amount of moistening of the electrodes in this experiment and resulting distribution of density in the potassium vapor. The reversal is nevertheless entirely unsymmetrical in respect to distribution of wave-lengths and intensity within the line. It appears displaced from the middle toward the violet. The violet component is weak and diffuse, while the red is strong and in sharp contrast at the reversal, gradually weakening toward the side of longer wave-lengths. This is true of both lines. At the lower density, which must be pretty near the critical density for the line λ4044, while it is considerably lower for λ4047, only the first line is reversed. The location of the reversal cannot be sharply determined, however, as the absorption is not sufficient to produce any considerable difference of intensity between the position of the reversal and the violet component. The line λ4047, contrariwise, shows no phenomenon of reversal. The maximum is slightly indicated, and the line is broad and very diffuse, especially toward the red. This line also gives the greatest displacement, 0.295 tenth-meters, as compared with the lowest concentration employed. Corresponding to this the line also exhibits in the arc-spectrum a quite considerable lack of symmetry in the location of the reversal with respect to the middle of the line and in the ratio of intensities of the two components, at a density only slightly above the critical density.

A pictorial representation of these peculiarities is necessary for their comprehension, but a reproduction of the lines themselves, even when much enlarged, is impractical and worthless, as the finer details of these are lost in the necessarily long route from the original to the engraving. We have therefore attempted



1. Arc C = 20; 2. Arc. C = 200; 3. Spark C = 200, lines reversed; 4. Spark C = 200, lines not reversed. The points measured are marked with a vertical line.

to reproduce the character of the lines in the accompanying curves. Of course they do not give us the same result that we should get from the direct enlargement of the original plates. Even with the greatest care in making the drawing, it is impossible to escape from subjective impressions which possibly affect the positions of the edges and the maxima of intensity, etc., less than the estimates of intensity. Measures are hardly possible with the slight breadth, and moreover they would scarcely give us an accurate picture since the changes of intensity with wavelength within a line are very considerable.

The curves are constructed from the screen according to the positions of the maxima, the edges of the reversals and the lines. But the heights of the ordinates which correspond to the intensity of the lines depend on mere estimate. Therefore the corresponding curves of different concentrations in this respect are not comparable with one another; on the other hand the respective vapor densities are quite comparable, especially 3 and 4. In fact the curves were taken from the same plates. It should be further remarked in respect to the arrangement that the wavelength curves are oriented according to convenience. The position of the reading is indicated by a vertical line.

We shall attempt in what follows to find an explanation for the observed facts. We must endeavor therefore to form a conception of the constitution of the luminous vapor. We shall concern ourselves in the next place with the arc. It is clear that when we are considering temperature and density that we must distinguish between the mantle of the arc and its core. The latter is always hotter than the enveloping layers because these are in contact with an environment which is cooler, and by convection and radiation part with a portion of their heat energy. The inner layers on the contrary are shielded and remain at a higher temperature. We have therefore a fall of temperature, although perhaps small, from the inner to the outer regions of the arc. At the same time, moreover, the vapor density is variable in a direction perpendicular to the arc. In the layers at the surface of the mantle small particles diffuse out from the arc, cool off and contribute little or nothing to the radiation. Especially at small densities is the influence of this shown so that we observe almost solely light from only the interior of the arc. But in all cases the line is composed of an infinite number of lines each of which corresponds to a distinct temperature and density of the luminous vapor.

The superposition of the intensity curves produces those observed, and the character of the line will be influenced most by those intensities which occur most frequently with small variation, these giving the average values. If we increase the concentration and therefore the density of the luminous vapor we will in the first place increase the intensity of the lines because the number of radiating centers is increased. At the same time the breadth of the line increases. Wave-lengths, further, come under observation which at lower temperatures have not figured. The wave-length also increases because as a consequence of greater density and resulting crowding of the particles toward one another, the forces which they mutually exert increase. This damping action is of course greater in the inner portion of the vapor than in the outer. Because, as a result of the higher temperature of the core, the energy of the radiation arising from within is greater than that from without, therefore we observe in the line a wave-length corresponding to a portion of the core. But the relation alters at the critical density.

It is therefore clear that we may regard the resulting intensity curve as having its origin in two, the emission and the absorption curve. Light which has come from the inner portion of the luminous vapor suffers in its passage into all the layers an absorption proportional to its emission.

If this increases to such an extent that a self-reversal is seen, we shall have superposed upon the emission curve of the strongly displaced line which corresponds to the central radiation, the absorption curve of the edge, which, on account of the lower temperature and less density in this region, shows a slighter displacement. Hence the reversal appears unsymmetrical and narrow, corresponding to the relatively low emission of the edge radiations. The more the density increases, the deeper are the layers of gas which share in the reversal; hence, just so much broader the reversal, and greater the displacement toward the red. Indeed, in the case of layers which lie beneath the critical one, we naturally observe absorption, only we do not then say that the line is self-reversed. In this case the absorption curve, which corresponds to its slighter displacement, lies principally above the violet part of the emission curve, which is therefore weakened toward the red. The line consequently seems to be diffuse toward the red, as is readily understood. In consequence of the absorption, which, of course, in the case of a self-reversal is not limited to that alone, the intensities of the components fall—a conclusion which seems to be supported by experience. The maximum intensity is observed in the vicinity of the critical density. Still more striking than in the case of the arc are the relations in the spark, in which as well the pressure plays a certain part. For the spark the temperature and density differences between the interior and surface are evidently still greater than in the case of the arc.

On the basis of Schuster's investigations I have elsewhere[1] developed the view that the pressure and the temperature of the spark depend to a considerable extent upon the velocity of the particles. It is then clear that at the surface of the spark the motion of translation of the particles, owing to friction with the surrounding gas, must be considerably less than in the interior, where all the particles describe sensibly parallel paths. In addition, therefore, to the fact of the cooling of the gas mantle through the radiations it emits, a cooling found in the arc as well, comes the circumstance that, for the reasons given, the temperature originally has a lower value than in the interior. The fall of temperature is therefore greater than in case of the arc. In consequence of the high pressure prevailing in the interior, the displacement of the line originating from the core is greater than for the arc. But as the fall of density is also greater in case of the spark, we observe as the resulting wave-length one corresponding to a less density than when an equal amount of material is introduced into the arc; since the average value of temperature and density at which we observe lies lower for the spark than for the arc, the conditions of the core being assumed to be the same.

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[1] E. HASCHEK, "Druck und Temperatur im elektrischen Funken." *Sitzungsberichte*, etc., 109, Abth. IIa, 1900.

This assumption would apply pretty closely in these experiments. Hence the explanation why at low concentrations the wave-length in the spark is smaller than in the arc.

If we now increase the density still lower strata will prevail in the intensity curve, on account of the more rapid increase of their emission. The intensity in the interior will increase in proportion to the number of luminous particles, while at the surface the currents and diffusion will remain the same, the cooling effect of the friction increasing. Larger displacements than in the arc will now appear on account of the interior pressure, since not only the increased density but also the pressure contributes to the closing in of the particles. Hence the emission increases more rapidly from the core than from the outside. Therefore the absorption of the exterior portions will not become effective until later, that is, the critical density will lie higher, as appears to be confirmed by experience. But before this is attained we shall notice in the spark as in the arc the absorption at the violet edge of the line. Since the maximum lies further toward the red for the spark, we shall get very diffuse lines, shaded off toward the red for the same reasons as in case of the arc. This absorption at the violet edge also remains, however, at the critical and higher densities. There should also be observed a weakening of the violet component in addition to the reversal, as is also found in fact.

The above results may be summarized as follows: With increasing density of the luminous vapor, displacements occur both in the arc and spark spectrum. These affect the lines as well as their reversals — a phenomenon due to the constitution of the luminous vapor.

III. ON THE DEPENDENCE OF THE WAVE-LENGTHS UPON THE MODE OF PRODUCTION OF THE LUMINOUS VAPOR.

In the discussion of the effect of the density upon the wave-length in the previous section, we have already emphasized the difference between the arc and spark spectra. We saw that the shift for an equal increase of concentration was greater for the spark than for the arc spectrum. A cause of this was found on the one hand in the pressure developed in the spark, and on the other in the greater contrasts in temperature and density than in the arc. It is therefore clear that all variations in the production of the luminous vapor will be accompanied by corresponding changes in the wave-length of the emitted lines, wholly aside from the changes in the character of the spectrum as a whole.

The above mentioned paper on the pressure in the spark furnishes us a guide for investigation. Indeed all conditions which alter the pressure must exert an influence on the wave-length. The difference in pressure between the transformer and the Ruhmkorff coil is most conspicuous, and is explained by the different consumption of energy. But, moreover, with similar pieces of apparatus differences arise, namely, with variable capacity, and also with the pressure and character of the enveloping gas.

The influence of these last mentioned conditions is clearly shown by J. F. Mohler's[1] paper on "Pressure in the Electric Spark," which I will here briefly review. Mohler worked with an induction coil which without capacity gave a spark of some 20 cm. Measured capacities (from 11.1 to 70.2 meters) were inserted in photographing the spectrum, and the spark length used was 3 mm or less. Cadmium served as electrodes so that in all cases the maximum vapor density was attained. It appeared that the wave-length increased with the capacity employed, from 0.026 tenth-meters, with 11.1 meters capacity, up to 0.088 tenth-meters at 70.2. Unfortunately the measurements for the lines chosen (λλ 5086.001, 4800.097, 4678.339) are not given separately, but merely the mean obtained from the measured values reduced to those at λ 4000. Therefore it is not possible to see whether all the lines were affected in the same way. It is worth noting that the displacement increases at first more rapidly, then more slowly with the capacity, and that it clearly approaches a maximum, just as E. Haschek and H. Mache found to be the case with pressure due to the spark. Therefore it appears that this alone is a determining condition. Mohler investigated the influence of the pressure and the character of the surrounding gas at constant capacity. In the first case he found an increase in shift proportional to the increase of pressure of the surrounding medium. He used carbon dioxide instead of air; the displacement increased in the ratio of 1.38 to 1.

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[1] J. F. Mohler, Astrophysical Journal, **10**, 1899.

We should here cite also the experiments of J. Wilsing,[1] who caused the spark to pass under water. The shift observed in this case was very marked, reaching in some cases the value of several units.

The comparison of spectra obtained with a Ruhmkorff coil fitted with different interrupters is important. I used an induction coil, which without a condenser gave a spark about 12 cm long between spherical terminals; and employed both the ordinary hammer and the Wehnelt electrolytic interrupter. A condenser battery of about 60 meters capacity was inserted in the secondary circuit. The experiment was performed with a 20 per cent. solution of caustic potash, due regard being paid to the precautionary rules previously given. The following table gives the wave-lengths measured.

It must be noted that in contrast with the lines given by the transformer those here obtained are weak and very diffuse, so that possibly an error of 0.02 tenth-meters may occur. For this reason the wave-length numbers previously given for the high-tension transformer are shortened to two decimals.

	INDUCTION COIL	
Transformer	Wehnelt Break	Hammer Break
4044.38	4044.36	4044.44
4047.45	4047.41	4047.47

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[1] J. WILSING, ASTROPHYSICAL JOURNAL, 10, 113, 1899.

Therefore it here again appears that the lines are strongly displaced: fairly equally in the case of the Wehnelt break and the transformer, but more strongly with the hammer break. The explanation for this may lie in the fact that with the small number of sparks (about 150 a minute) the air in the region of the spark's path is entirely cooled again, so that a strong fall in temperature is present. The state of things may be analogous to the pressure relations. The discharge has to break its way through the medium afresh. The particles at the periphery are hemmed in very strongly. A strong displacement is therefore observed which corresponds to the maximum pressure, while the mean pressure lies lower. This explanation is favored by the circumstance that the lines are very diffuse, and do not possess an especially well marked intensity maximum.

In closing it may further be noted that with the induction coil the times of exposure were quite considerable; with the hammer break they were 400 seconds; with the Wehnelt break 500, despite the great number of sparks. Therefore, on this account it is not advisable to use this break in photographing spectra. Nevertheless, the numbers given show that we can with full justification apply to the induction coil the wave-lengths obtained with the high potential transformer.

A valuable conclusion relative to the limits of accuracy in measurement may be drawn from the results of this and the previous sections. We have seen that displacements of lines are common to both arc and spark spectra, and under certain conditions attain considerable magnitudes. The spectrum of the spark especially shows strong shifts which reach 0.2 tenth-meters for elements which are rich in lines, but 0.7 tenth-meters for those which have few lines in their spectrum. The observed value of the wave-length is, as was shown, dependent, to a high degree, upon the momentary conditions of the experiment, and these are, in many cases, not at all subject to control. This is seen especially in the case of the density of the luminous vapor. Therefore, in most cases, especially in dealing with the identification of lines, we may satisfy ourselves with an accuracy of measurement which neglects the shift of the lines, at least as long as the possible variation for every line of every element is unknown. And this task is scarcely capable of execution. If, now, we are to assign a limit of accuracy, 0.03 tenth-meter ought to serve well for elements rich in lines, and 0.1 tenth-meter for those poor in lines. The first set of spectra shows lines easily measurable with an accuracy of 0.03, which generally present little shift; while elements whose spectra are characterized by great shifts give lines which are very broad and not easily measured. These deductions hold, of course, only when the spectra of composite substances are being spectroscopically examined for purposes of identification. In such cases we draw our conclusions from the agreement of a number of lines. But if we are dealing with the change of wave-lengths by external causes, investigating the homogeneity of lines and similar problems — in short, studying lines as such — then we should strive to attain to the greatest possible accuracy of wave-length measurement. However, in these cases, an approximate value of the wave-length will suffice, if only the changes be determined with sufficient sharpness. And this problem is incomparably the easier one.

The question now arises as to how far the measurements of wave-lengths which hold for the transformer spectrum are transferable to spark spectra obtained with the Ruhmkorff coil — a question which cannot, in general, be answered. As shown by the foregoing investigation, the wave-length of the lines is dependent, to a high degree, upon the energy consumed. But the consumption of energy with the transformer is very great; some lines are, therefore, shifted strongly toward the red. The Ruhmkorff coil also gives nearly an equal displacement under conditions like those described above. But the conclusion that in all cases the induction coil and transformer give equal shifts is inadmissible — for example, certainly not with small instruments which are fed with battery or storage-cell currents. Lower values than with the transformer will then obtain for the shifted lines, which will be in any case in the minority. We may assume, moreover, as a rule, that lines of an element which enter as an impurity are undisplaced; or we may state with more exactness that if the limit of error of measurement be chosen such that it lie in the hundredths place, then the shift is smaller than the error of measurement, and will therefore be concealed. Therefore, we can assume, but with considerable reserve, that the transformer wave-lengths hold true for the Ruhmkorff spectrum, and that considerable differences enter only in cases of small apparatus and for but a few lines. But despite this, errors in the identification of lines can scarcely enter, because a whole series of lines is always considerd and never single lines.

NOTE.—An attempt has been made at the Yerkes Observatory to verify the results obtained by Professor Haschek. In the first instance Professor C. E. St. John and Dr. N. E. Kent used a Littrow spectroscope with 5-inch plane grating, having 20,000 lines to the inch (first order) and combined collimator and camera objective of 18 feet focal length. The large induction coil was supplied with current from a 3-kilowatt alternating dynamo, run at about 1400 revolutions per minute, and giving about 90 complete cycles per second. The capacity of the condenser, which was connected in parallel with the secondary coil, ranged from 0.003 to 0.024 microfarads. In a second series of experiments made by Dr. Kent the second-order spectrum of a 6-inch concave grating having 15,000 lines to the inch was used, and a transformer giving 30,000 volts was substituted for the coil. The capacity of the condenser ranged from 0.007 to 0.07 microfarads. The spectra of arc and spark were in all cases photographed on the same plate. The maximum displacements observed for the titanium lines in Haschek's table did not exceed 0.04 tenth-meter, and are thus much smaller than his values. Whether this lack of agreement is to be attributed to different electrical conditions or to some other cause cannot as yet be determined. It may be remarked, however, that differential measures of arc and spark lines on the same plate might reasonably be expected to yield more accurate results than the method of comparison uesd in the first section of Haschek's article. In view of the importance of the subject, and its bearing upon various astrophysical problems, it is hoped that the experiments will be repeated elsewhere.— ED.

MINOR CONTRIBUTIONS AND NOTES

OBSERVATIONS OF THE SPECTROSCOPIC BINARY *η PEGASI*.[1]

THE binary character of *η Pegasi* was discovered in August, 1898, from observations made with the Mills spectroscope, and announced in the ASTROPHYSICAL JOURNAL for October, 1898. It was the first one of some thirty-five spectroscopic binary systems discovered in the past three years with this efficient instrument. As a basis for determining the orbit of the bright component of this system, the following velocities in the line of sight were observed:

No.	Date, Greenwich M. T.			Velocity Kilometers	No.	Date, Greenwich M. T.			Velocity Kilometers
1	1896	August	27.8	+ 7.10	16	1899	June	21.0	− 8.02
2		September	23.7	+ 5.10	17		June	27.0	− 8.31
3	1897	July	8.9	− 6.37	18		July	26.9	− 7.14
4		September	28.7	− 2.21	19		September	6.8	− 6.81
5	1898	August	29.8	+ 16.54	20		December	19.7	− 3.86
6		August	30.8	+ 15.62	21		December	25.7	− 1.44
7		September	4.7	+ 16.46	22	1900	May	14.0	+ 10.89
8		September	15.8	+ 15.74	23		June	7.0	+ 14.06
9		October	18.7	+ 10.99	24		August	1.9	+ 18.89
10		October	24.8	+ 11.51	25		September	25.7	+ 21.40
11		October	26.8	+ 10.83	26		October	9.7	+ 20.37
12		November	28.7	+ 6.06	27		October	24.8	+ 19.88
13	1899	January	23.6	− 0.84	28		December	11.7	+ 15.17
14		May	2.0	− 6.44	29	1901	May	9.0	− 0.18
15		May	9.0	− 5.94					

The period of revolution of the system was early found to be about two years and a quarter. The observations are distributed over more than two complete periods.

The probable error of one observation, ± 0.47 kilometer, determined by Dr. Crawford, is very satisfactory under the circumstances. It is based upon all the observations secured. These include those made in 1896, with a very imperfect camera lens. The first thirteen observations were obtained before the special temperature control was installed.

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[1] *Lick Observatory, University of California, Bulletin* No. 5.

The thirteenth observation was made when the star was low in the west, in the early evening, with the temperature changing rapidly. Experience has shown that observations taken under such conditions are not only useless, but are apt to be harmful, and No. 13 might well have been rejected. It furnishes the largest residual, and its rejection would have reduced very materially the computed probable error of a single observation.

The spectra were measured, in all cases, soon after they were secured, in six different years. The 26th, 27th, and 28th plates were measured and reduced by Dr. Reese, and the remaining twenty-six plates by myself. If they could have been measured in quick succession, by one observer, no doubt the results would yield a much smaller computed probable error, as the personal habits of measurement change appreciably with time.

Messrs. Hussey and Aitken have carefully examined *η Pegasi* with the 36-inch refractor, but have been unable to detect the companion star.

W. W. CAMPBELL.

1901, July 24.

THE ORBIT OF THE SPECTROSCOPIC BINARY *η PEGASI.*

This orbit of *η Pegasi* is based upon the twenty-nine observations given above by Director Campbell. Of these, several groups have been formed into normal positions by taking the mean of their dates and of their velocities. These groups are Nos. 5, 6, 7, 8; 9, 10, 11; 14, 15; 16, 17; and 20, 21. To these will be given the numbers N_1, N_2, etc. Their data are as follows:

No.	Date, Greenwich M. T.	Velocity Kilometers.	Wt.
N_1	1898 September 4.8	+ 16.09	4
N_2	October 23.4	+ 11.11	3
N_3	1899 May 5.5	− 6.19	2
N_4	June 24.0	− 8.16	2
N_5	December 22.7	− 2.65	2

All of the other observations have been given weight unity, except No. 13, to which, for reasons given by Director Campbell, weight one-half has been assigned.

From the plot of these observations the first approximation to the period was taken to be 815 days. By adjusting the upper and the lower areas to equality by means of a planimeter, the velocity of the center of mass of the system was found to be $+4.15$ km.

Using the formulæ and notation of Lehmann-Filhés, the following preliminary constants and elements have been obtained:

PRELIMINARY ELEMENTS.

$A = 16.85$ km $\qquad B = 12.05$ km
$z_1 = +0.429 \qquad z_2 = -0.482$
$K = 14.45$
$e = 0.176$
$\omega = 19^\circ\!.056$
$\mu = 0.007709$ rad.
$= 0^\circ\!.4417$
$T = 1898$, Aug. 3.0
$V_0 = +4.15$ km
$U = 815.0$ days
$a \sin i = 159,420,000$
$[pvv]_n = 19.55$

The residuals resulting from these elements are given in the table at the end. From these elements and the residuals, the following twenty-one weighted, homogeneous observation equations were set up:

No.	a	b	c	d	e	f	n
1.....	0.254 u	−1.443 v	−1.522 w	+1.223 x	+1.337 y	+1.000 z	+0.720 = 0
2.....	0.014	−1.580	−1.511	+1.081	+1.228	+1.000	−0.750 = 0
3.....	−0.744	+1.258	+0.517	−0.167	−0.330	+1.000	−0.220 = 0
4.....	−0.464	+0.235	+1.039	−0.262	−0.656	+1.000	−0.350 = 0
N_1 ...	1.866	+1.256	−2.020	−0.086	−2.032	+2.000	+3.080 = 0
N_2 ...	0.900	−1.552	−2.481	−0.247	+2.339	+1.730	+0.969 = 0
12....	0.182	−1.521	−1.528	−0.200	+1.312	+1.000	+0.720 = 0
13....	−0.192	−0.896	−0.977	−0.143	+0.711	+0.707	+0.749 = 0
N_3 ...	−1.056	+0.834	−0.949	−0.182	+0.510	+1.414	−0.650 = 0
N_4 ...	−1.168	+1.714	−0.376	−0.062	+0.148	+1.414	+0.537 = 0
18....	−0.832	+1.409	+0.003	+0.022	−0.048	+1.000	−0.730 = 0
19....	−0.792	+1.399	+0.331	+0.118	−0.227	+1.000	−0.490 = 0
N_5 ...	−0.656	+0.332	+1.509	+0.609	−0.928	+1.414	+0.127 = 0
22....	0.444	−1.487	+1.309	+0.927	−1.101	+1.000	−0.460 = 0
23....	0.617	−1.303	+1.207	+0.954	−1.092	+1.000	−0.990 = 0
24....	0.997	−0.028	+0.721	+0.752	−0.804	+1.000	−0.330 = 0
25....	1.166	+1.349	−0.061	+0.025	−0.024	+1.000	−0.400 = 0
26....	1.156	+1.452	−0.284	−0.231	+0.223	+1.000	+0.490 = 0
27....	1.119	+1.390	−0.521	−0.516	+0.489	+1.000	+0.440 = 0
28....	0.836	+0.213	−1.156	−1.290	+1.155	+1.000	+1.060 = 0
29....	−0.404	−0.936	−1.270	−1.139	+0.870	+1.000	−1.510 = 0

Where $u = \delta K$; $v = 10\,\delta e$; $w = 10\,\delta\omega$; $x = 10{,}000\,\delta\mu$; $y = \frac{1}{10}\delta T$; and $z = \delta V_0$.

From these equations the following normal equations result (the coefficients are given by their logarithms):

1	1.198822 u	+0.322426n v	+0.817499n w	+9.397940 x	+0.809492 y	+0.665675 z	+0.955303 = 0
2	0.322426n	+1.501004	+0.756408	+0 760875n	+0.670060n	+0.565021	+0.544068 = 0
3	0.817499n	+0.756408	+1.475599	+0.673021	+1.405858n	+1.060244n	+1.084219n = 0
4	9.397940	+0.760875n	+0.673021	+0.950754	+0.609914n	+0.046495	+0.320977n = 0
5	0.809492	+0.670060n	+1.405858n	+0.609914n	+1.348110	+1.023828	+1.087320 = 0
6	0.665675	+0.565021	+1.060244n	+0.046495	+1.023828	+1.454692	+0.747179 = 0

The solution of these gives

$\delta K = -0.29$ km ± 0.12 km
$\delta e = -0.0264$ ± 0.0091
$\delta\omega = -11\overset{\circ}{.}143$ $\pm 2\overset{\circ}{.}822$
$\delta\mu = -0.000023$ rad. ± 0.000018 rad.
$= -0\overset{\circ}{.}00132$ $\pm 0\overset{\circ}{.}00101$
$\delta T = -28.6$ days ± 5.9 days
$\delta V_0 = +0.17$ km ± 0.10 km
$\delta U = +2.4 +$ days ± 1.9 days

For these corrections the following elements result:

SECOND ELEMENTS.

$K = 14.16$ km
$e = 0.1496$
$\omega = 7\overset{\circ}{.}913$
$\mu = 0.007686$ rad,
$= 0\overset{\circ}{.}44038$
$T = 1898$, July 5.4
$V_0 = +4.32$ km
$U = 817.4 +$ days

$[pvv]_n = 6.05$ from the observation equations. The probable errors given above were obtained from this $[pvv]_n$.
$[pvv]_n = 6.55$ from the ephemeris residuals.
$[pvv] = 11.33$.

NOTE.— $[pvv]_n$ means the $[pvv]$ resulting from using the residuals from the normal places instead of from the individual observations. When the latter are used no subscript will appear with the symbol $[pvv]$.

The resulting probable error of a single observation is:

$r = \pm 0.43$ km from the first $[pvv]_n$.
$r = \pm 0.474$ km from $[pvv]$.

The velocities and the corresponding residuals computed from these elements are shown in the table at the end. This table gives also the differences between the residuals as found from the elements and from the observation equations. This column is headed Δ_1. From these differences it is seen that the terms involving the second powers of the increments in the differential equations of condition are not negligible. This discrepancy necessitated another solution, starting from the second element.

From these elements the following weighted, homogeneous observation equations result:

No.	a	b	c	d	e	f	n
1	0.212u	−1.472v	−1.442w	+1.049x	+1.192y	+1.000z	+0.230=0
2	−0.007	−1.455	−1.428	+0.935	+1.106	+1.000	−0.880=0
3	−0.766	+1.113	+0.537	−0.155	−0.330	+1.000	−0.160=0
4	−0.470	−0.092	+1.084	−0.256	−0.705	+1.000	−0.120=0
N_1	1.730	+0.266	−2.034	−0.158	+1.972	+2.000	+0.940=0
N_2	0.826	−1.931	−2.366	−0.321	+2.101	+1.732	−0.052=0
12	0.167	−1.492	−1.445	−0.224	+1.179	+1.000	+0.630=0
13	−0.182	−0.713	−0.936	−0.176	+0.669	+0.707	+1.075=0
N_3	−1.046	+0.966	−0.960	−0.223	+0.563	+1.414	+0.042=0
N_4	−1.181	+1.769	−0.402	−0.097	+0.211	+1.414	+0.919=0
18	−0.852	+1.406	−0.015	+0.004	−0.008	+1.000	−0.600=0
19	−0.820	+1.327	+0.323	+0.113	−0.203	+1.000	−0.490=0
N_5	−0.682	−0.068	+1.513	+0.683	−0.980	+1.414	+0.198=0
22	0.490	−1.301	+1.302	+0.992	−1.125	+1.000	+0.370=0
23	0.677	−0.910	+1.172	+0.982	−1.075	+1.000	−0.150=0
24	1.034	+0.575	+0.627	+0.647	−0.657	+1.000	+0.070=0
25	1.145	+1.417	−0.147	−0.131	+0.124	+1.000	−0.870=0
26	1.121	+1.336	−0.354	−0.367	+0.341	+1.000	−0.170=0
27	1.073	+1.109	−0.567	−0.614	+0.561	+1.000	−0.360=0
28	0.788	−0.178	−1.117	−1.235	+1.067	+1.000	+0.310=0
29	−0.371	−0.802	−1.239	−1.149	+0.581	+1.000	−0.760=0

Where, as before, $u=\delta K$; $v=\delta e$; $w=10\,\delta\omega$; $x=10{,}000\;\delta\mu$; $y=\frac{1}{10}\,\delta T$; and $z=\delta V_0$. From these equations the following normal equations were computed (coefficients logarithmic).

1	1.181433u	+0.590730n v	+0.783868n w	+9.398808n x	+0.759441 y	+0.609594z	+9.680789 =0
2	0.590730n	+1.453624	+0.886378	+0.035685n	+0 798547n	+0.015360	+0.308137n=0
3	0.783868n	+0.886378	+1.454387	+0.765929	+1.372258n	+1.053981n	+0.283075n =0
4	9.398808n	+0.635685n	+0.765929	+0.932068	+0.704751n	+9.033424	+9.155336 =0
5	0.759441	+0.798547n	+1.372258n	+0.704751n	+1.299202	+1.003590	+0.252125 =0
6	0.609594	+0.015360	+1.053981n	+9.033424	+1.003590	+1.454799	+0.093071 =0

The solution of these gives:

$\delta K = +0.04$ km	± 0.12 km	± 0.13 km
$\delta e = +0.0052$	± 0.0098	± 0.0106
$\delta\omega = -2^{\circ}.308$	± $3^{\circ}.430$	± $3^{\circ}.708$
$\delta\mu = -0.000005$ rad.	± 0.000019 rad.	± 0.000020 rad.
$= -0^{\circ}.00029$	± $0^{\circ}.00108$	± $0^{\circ}.00117$
$\delta T = -5.7$ days	± 7.5 day	± 8.1 days
$\delta V_0 = -0.01$ km	± 0.10 km	± 0.10 km
$\delta U = +0.5$ days	± 2.0 days	± 2.2 days

$[pvv]_n = 6.21$

$[pvv] = 11.13$

$r = \pm 0.43$ from $[pvv]_n$

$r = \pm 0.469$ from $[pvv]$

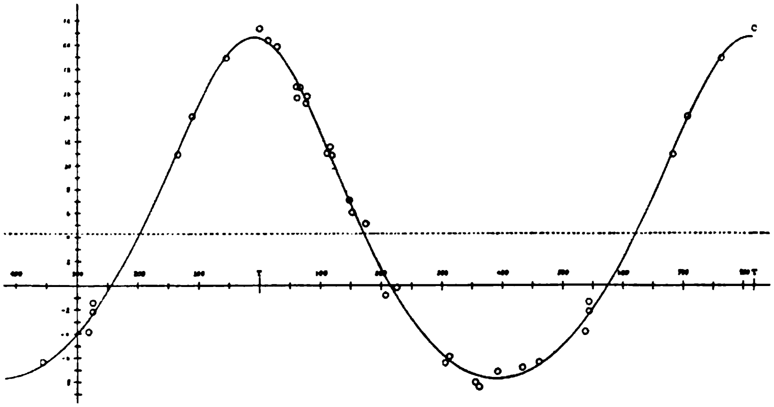
The first set of probable errors given after the corrections to the elements has been derived from the first r; the second set from the second r. The latter, depending upon the residuals from the individual observations, is the more reliable.

Applying these corrections to the second elements given above, the following final elements result:

FINAL ELEMENTS.

K	$= 14.20$ km	± 0.13 km
e	$= 0.1548$	± 0.0106
ω	$= 5^\circ.605$	$\pm 3^\circ.708$
μ	$= 0.007681$ rad.	± 0.000020 rad.
	$= 0^\circ.44009$	$\pm 0^\circ.00117$
T	$=$ 1898, June 29.7	$\pm$ 8.1 days
	$=$ 1900, Sept. 25.7	
V_0	$= +4.31$ km	± 0.10 km
U	$= 818.0$ days	± 2.2 days
$a \sin i$	$= 157{,}800{,}000$	

The velocities and the corresponding residuals computed from these elements are shown in the table at the end. The differences between the residuals as found from these elements and from the observation equations are placed in the column Δ_2. They show this final solution to be satisfactory.



The curve in the accompanying figure is that of the final elements. The observations are represented by the small circles. The intervals shown on the *X* axis are fifty days. The zero is at the place representing the time of periastron (*T*). One division on the *Y* axis represents a velocity of one kilometer per second. The dotted line indicates the velocity of the center of mass of the system. The maximum velocity is +20.70 km per second and the minimum is −7.70 km per second.

TABLE.

No.	V	Wt.	ELEMENTS—I.		ELEMENTS—II.		Δ_1	ELEMENTS—III.		Δ_2
			V	O.—C.	V	O.—C.		V	O.—C.	
	$\frac{km.}{sec.}$		$\frac{km.}{sec.}$	$\frac{km.}{sec.}$	$\frac{km.}{sec.}$	$\frac{km.}{sec.}$		$\frac{km.}{sec.}$	$\frac{km.}{sec.}$	
1	+ 7.10	1	+ 7.82	−0.72	+ 7.33	−0.23	0.18	+ 7.10	±0.00	0.00
2	+ 5.10	1	+ 4.35	+0.75	+ 4.22	+0.88	0.11	+ 4.04	+1.06	0.01
2	− 6.37	1	− 6.59	+0.22	− 6.53	+0.16	0.02	− 6.57	+0.20	0.04
4	− 2.21	1	− 2.56	+0.35	− 2.33	+0.12	0.07	− 2.39	+0.18	0.01
5	+16.54	1	......	.....	+17.14	−0.60	...	+17.03	−0.49	...
6	+15.62	1	......	.....	+17.04	−1.42	...	+16.93	−1.31	...
7	+16.46	1	......	.....	+16.57	−0.11	...	+16.45	+0.01	...
N_1	+16.09	4	+17.63	−1.54	+16.56	−0.47	0.12	......	.....	0.04
8	+15.74	1	......	.....	+15.44	+0.30	...	+15.19	+0.55	...
9	+10.99	1	......	.....	+11.65	−0.66	...	+11.47	−0.48	...
N_2	+11.11	3	+11.67	−0.56	+11.08	+0.03	0.21	......	.....	0.01
10	+11.51	1	......	.....	+10.91	+0.60	...	+10.73	+0.78	...
11	+10.83	1	......	.....	+10.67	+0.16	...	+10.48	+0.35	...
12	+ 6.06	1	+ 6.78	−0.72	+ 6.69	−0.63	0.13	+ 6.53	−0.47	0.00
13	− 0.84	½	+ 0.22	−1.06	+ 0.68	−1.52	0.01	+ 0.62	−1.46	0.00
14	− 6.44	1	......	.....	− 6.02	−0.42	...	− 5.97	−0.47	...
N_3	− 6.19	2	− 6.65	+0.46	− 6.16	−0.03	0.05	......	.....	0.00
15	− 5.94	1	......	.....	− 6.30	+0.36	...	− 6.25	+0.31	...
16	− 8.02	1	......	.....	− 7.46	−0.56	...	− 7.41	−0.61	...
N_4	− 8.16	2	− 7.78	−0.38	− 7.51	−0.65	0.05	......	.....	0.00
17	− 8.31	1	......	.....	− 7.55	−0.76	...	− 7.50	−0.81	...
18	− 7.14	1	− 7.87	+0.73	− 7.74	+0.60	0.04	− 7.70	+0.56	0.00
19	− 6.81	1	− 7.30	+0.49	− 7.30	+0.49	0.01	− 7.29	+0.48	0.00
20	− 3.86	1	......	.....	− 2.71	−1.15	...	− 2.80	−1.06	...
N_5	− 2.65	2	− 2.56	−0.09	− 2.51	−0.14	0.10	......	.....	0.00
21	− 1.44	1	......	.....	− 2.30	+0.86	...	− 2.39	+0.95	...
22	+10.89	1	+10.43	+0.46	+11.26	−0.37	0.01	+11.27	−0.38	0.00
23	+14.06	1	+13.07	+0.99	+13.01	+0.15	0.05	+13.98	+0.08	0.01
24	+18.89	1	+18.56	+0.33	+18.96	−0.07	0.22	+19.12	−0.23	0.01
25	+21.40	1	+21.00	+0.40	+20.53	+0.87	0.13	+20.63	+0.77	0.00
26	+20.37	1	+20.86	−0.49	+20.20	+0.17	0.08	+20.27	+0.10	0.00
27	+19.88	1	+20.32	−0.44	+19.52	+0.36	0.01	+19.55	+0.33	0.00
28	+15.17	1	+16.23	−1.06	+15.48	−0.31	0.14	+15.40	−0.23	0.00
29	− 0.18	1	− 1.69	+1.51	− 0.94	+0.76	0.03	− 0.92	+0.74	0.01

RUSSELL TRACY CRAWFORD.

July 24, 1901.

OPPOSITION OF *EROS* (433) IN 1903.[1]

THE planet *Eros* is now so near the Sun that further observations of its light have become impossible. At the same time sufficient material has not been accumulated since the discovery of its variation in light, to determine satisfactorily the laws governing it. It is, therefore, a matter of no little interest to learn when further observations can be obtained. Since three times the tropical period is about seven years, the favorable conditions of 1893 and 1900 will not recur until 1907. The next oppostion will occur in 1903, under conditions similar to those in 1896. The planet was then so far south that had its existence been known at that time it could not have been observed

TABLE I

COMPUTED POSITIONS.

J. D.	Date 1901-3			R. A. 1900		Dec. 1900		log r	log Δ
	y	m	d	h	m				
5501	01	4	26	8	39.1	— 0°	38′	0.1025	9.8251
5506		5	1	8	54.7	— 1	41	0.1076	9.8447
5516		5	11	9	25.2	— 3	44	0.1179	9.8841
5556		6	20	11	20.4	—11	23	0.1587	0.0340
5596		7	30	13	7.4	—18	11	0.1939	0.1657
5636		9	8	14	51.6	—23	24	0.2208	0.2732
5676		10	18	16	36.6	—25	59	0.2391	0.3543
5716		11	27	18	21.1	—25	2	0.2491	0.4085
5745		12	26	19	34.3	—21	59	0.2512	0.4310
5800	02	2	19	21	44.4	—11	21	0.2435	0.4364
5840		3	31	23	13.7	— 0	44	0.2281	0.4116
5880		5	10	0	45.7	+11	10	0.2041	0.3658
5920		6	19	2	31.4	+22	49	0.1717	0.3034
5960		7	29	4	44.7	+30	58	0.1323	0.2360
6000		9	7	7	24.1	+29	56	0.0914	0.1653
6040		10	17	9	56.7	+16	59	0.0610	0.1149
6080		11	27	12	8.3	— 2	48	0.0560	0.0796
6160	03	2	14	16	3.5	—33	57	0.1188	0.0251
6200		3	26	17	38.2	—40	43	0.1596	9.9540
6240		5	5	18	4.9	—44	38	0.1945	9.8539
6250		5	15	17	53.4	—45	0	0.2020	9.8331
6260		5	25	17	36.0	—44	43	0.2090	9.8197
6280		6	14	16	52.7	—41	24	0.2213	9.8276
6300		7	4	16	24.6	—35	54	0.2314	9.8832
6310		7	14	16	20.0	—33	18	0.2357	9.9221
6320		7	24	16	20.9	—31	5	0.2395	9.9642
6360		9	2	17	1.2	—25	55	0.2493	0.1252
6400		10	12	18	12.4	—23	3	0.2509	0.2475
6440		11	21	19	36.6	—19	1	0.2444	0.3294

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[1] *Harvard College Observatory Circular* No. 61.

readily, either in the United States or Europe. It accordingly becomes important to trace the path for the next two or three years. The positions have been computed by Miss Anna Winlock by means of the elements given by Millosevich (*A. N.*, 155, 25) for the dates with the results given above :

The intervals between these dates are so large, in some cases, that interpolation by the usual method is impossible. Moreover, only approximate positions are needed, since for a large portion of the time *Eros* will probably be too faint to be observed. To show the general form of its path, so as to prepare plans for observing it, the approximate ephemeris, given in Table II, has been determined graphically for every ten days. After trying various methods, curves were drawn, with Julian Days as abscissas, and ordinates equal to the four tabular quantities given in Table I. For each of these curves, the ordinate for every ten days was next read. First differences were taken, and points again plotted, with these differences, on a much larger scale, as ordinates. A smooth curve was drawn through these points, and the ordinates again read. Regarding these last readings as first differences, the original ordinates were approximately reproduced by successive summations. We thus obtain an ephemeris in which the accidental errors are very small, but which may differ systematically from the computed values, if the curve of first differences is drawn too high or too low. This systematic error was corrected by plotting points with abscissas equal to the Julian Day, and ordinates equal to the difference between the computed values and those given by the approximate ephemeris. These points should lie on a smooth curve, whose ordinates serve to correct the approximate ephemeris. In this way, we obtain an ephemeris, passing through all the computed points, in which the accidental errors are small. Systematic errors may enter between the computed points, since these portions of the curve are necessarily indeterminate, The results are given in Table II, the last column giving the magnitude, uncorrected for phase and assuming, as in *Circular* No. 49, that the magnitude at distance unity is 11.39.

It will be noticed that the earliest favorable time for observation is in the spring of 1903. It is expected that Professor Bailey will make an extensive series of photometric measures of *Eros* during this period at the Arequipa Station.

TABLE II.

APPROXIMATE EPHEMERIS OF *EROS*.

J. D.	Date 1901			R. A. 1900		Dec. 1900	log r	log Δ	Mag.
	y	d	m	h	m				
5500	01	4	25	8	36	— 0°.4	0.102	9.821	11.01
5510		5	5	9	7	— 2.5	0.112	9.860	11.25
5520		5	15	9	37	— 4.5	0.122	9.899	11.49
5530		5	25	10	6	— 6.6	0.131	9.937	11.73
5540		6	4	10	35	— 8.5	0.141	9.974	11.97
5550		6	14	11	3	—10.3	0.151	0.011	12.20
5560		6	24	11	31	—12.1	0.162	0.047	12.43
5570		7	4	11	58	—13.8	0.172	0.081	12.65
5580		7	14	12	25	—15.5	0.181	0.114	12.87
5590		7	24	12	52	—17.2	0.189	0.146	13.07
5600		8	3	13	18	—18.8	0.197	0.176	13.25
5610		8	13	13	44	—20.3	0.204	0.204	13.43
5620		8	23	14	10	—21.6	0.211	0.231	13.60
5630		9	2	14	36	—22.7	0.217	0.257	13.76
5640		9	12	15	2	—23.7	0.223	0.281	13.91
5650		9	22	15	28	—24.5	0.228	0.303	14.05
5660		10	2	15	54	—25.1	0.233	0.323	17.17
5670		10	12	16	20	—25.6	0.237	0.342	14.29
5680		10	22	16	47	—25°.9	0.240	0.360	14.39
5690		11	1	17	13	—26.1	0.243	0.376	14.49
5700		11	11	17	40	—25.9	0.245	0.390	14.57
5710		11	21	18	6	—25.6	0.247	0.402	14.63
5720		12	1	18	32	—25.0	0.249	0.413	14.70
5730		12	11	18	58	—24.1	0.250	0.422	14.75
5740		12	21	19	24	—22.9	0.250	0.429	14.79
5750		12	31	19	49	—21.5	0.250	0.434	14.81
5760	02	1	10	20	14	—19.8	0.249	0.437	14.82
5770		1	20	20	38	—18.0	0.248	0.439	14.83
5780		1	30	21	2	—16.0	0.247	0.439	14.82
5790		2	9	21	23	—13.7	0.246	0.438	14.81
5800		2	19	21	44	—11.3	0.244	0.436	14.79
5810		2	29	22	16	— 8.8	0.241	0.433	14.76
5820		3	11	22	28	— 6.2	0.238	0.427	14.71
5830		3	21	22	51	— 3.5	0.233	0.420	14.65
5840		3	31	23	14	— 0.7	0.228	0.412	14.59
5850		4	10	23	37	+ 2.2	0.224	0.402	14.52
5860		4	20	0	0	+ 5.2	0.219	0.391	14.44
5870		4	30	0	23	+ 8.2	0.213	0.379	14.35
5880		5	10	0	47	+11.2	0.204	0.366	14.25
5890		5	20	1	11	+14.1	0.197	0.351	14.13
5900		5	30	1	36	+17.0	0.190	0.335	14.01
5910		6	9	2	3	+20.0	0.181	0.319	13.89
5920		6	19	2	31	+22.8	0.172	0.303	13.77
5930		6	29	3	3	+25.4	0.162	0.287	13.63
5940		7	9	3	36	+27.7	0.152	0.270	13.50
5950		7	19	4	10	+29.6	0.142	0.253	13.37
5960		7	29	4	45	+31.0	0.132	0.236	13.23
5970		8	8	5	23	+31.7	0.121	0.218	13.09
5980		8	18	6	4	+31.8	0.111	0.199	12.94
5990		8	28	6	45	+31.2	0.101	0.181	12.80

TABLE II — *Continued.*

J. D.	Date 1901–3			R. A. 1900		Dec. 1900	log r	log Δ	Mag.
	y	m	d	h	m				
6000		9	7	7	24	+29.9	0.091	0.165	12.67
6010		9	17	8	3	+27.8	0.082	0.151	12.55
6020		9	27	8	42	+25.0	0.074	0.138	12.45
6030		10	7	9	20	+21.3	0.067	0.126	12.35
6040		10	17	9	57	+17.0	0.061	0.115	12.27
6050		10	27	10	32	+12.3	0.057	0.105	12.20
6060		11	7	11	5	+ 7.3	0.055	0.095	12.14
6070		11	17	11	37	+ 2.3	0.054	0.087	12.09
6080		11	27	12	8	— 2.8	0.056	0.080	12.07
6090		12	6	12	39	— 7.9	0.060	0.074	12.06
6100		12	16	13	9	—12.9	0.066	0.068	12.06
6110		12	26	13	39	—17.5	0.073	0.062	12.07
6120	03	1	5	14	9	—21.7	0.081	0.056	12.07
6130		1	15	14	38	—25.5	0.090	0.050	12.09
6140		1	25	15	7	—28.8	0.099	0.043	12.10
6150		2	4	15	35	—31.5	0.109	0.035	12.11
6160		2	14	16	3	—34.0	0.119	0.025	12.11
6170		2	24	16	30	—36.1	0.129	0.013	12.11
6180		3	6	16	55	—37.9	0.140	9.997	12.07
6190		3	16	17	18	—39.4	0.150	9.977	12.03
6200		3	26	17	38	—40.7	0.160	9.954	11.96
6210		4	5	17	54	—42.0	0.169	9.929	11.88
6220		4	15	18	5	—43.1	0.178	9.903	11.79
6230		4	25	18	9	—44.0	0.186	9.878	11.71
6240		5	5	18	5	—44.6	0.194	9.854	11.63
6250		5	15	17	54	—45.0	0.202	9.833	11.57
6260		5	25	17	36	—44.7	0.209	9.820	11.54
6270		6	4	17	14	—43.5	0.215	9.817	11.55
6280		6	14	16	53	—41.4	0.221	9.828	11.63
6290		6	24	16	36	—38.8	0.226	9.850	11.77
6300		7	4	16	25	—35.9	0.231	9.883	11.96
6310		7	14	16	20	—33.3	0.236	9.922	12.18
6320		7	24	16	21	—31.1	0.240	9.964	12.41
6330		8	3	16	27	—29.4	0.243	0.006	12.63
6340		8	13	16	36	—27.9	0.245	0.047	12.85
6350		8	23	16	47	—26.7	0.247	0.087	13.06
6360		9	2	17	1	—25.9	0.249	0.125	13.26
6370		9	12	17	17	—25.4	0.250	0.159	13.43
6380		9	22	17	34	—24.7	0.251	0.191	13.60
6390		10	2	17	52	—33.9	0.251	0.221	13.75
6400		10	12	18	12	—23.0	0.251	0.248	13.89
6410		10	22	18	32	—22.1	0.250	0.272	14.01
6420		11	1	18	53	—21.1	0.249	0.294	14.10
6430		11	11	19	15	—20.1	0.247	0.313	14.19
6440		11	21	19	37	—19.0	0.244	0.329	14.25

EDWARD C. PICKERING.

AUGUST 10, 1901.

THE INFERIOR CONJUNCTION OF *MERCURY* ON NOVEMBER 4, 1901.

In many popular astronomies a transit of *Mercury* is predicted for the 4th of November of this year. There actually will occur, however, only a close approach of the limbs of *Mercury* and the Sun, at the small distance of 165″, or one-twelfth of the Sun's diameter. It is not impossible that Mercury will be projected upon some prominences happening to be at the necessary position angle, although they would have to be of four times the average height, and would have to be detected by a prominence spectroscope or a spectroheliograph. Since the greatest elevation at which prominences have been observed is 11 28″, so far as I know (*A. N.* 3335), it has seemed to me to be sufficient to compute the relative co-ordinates for every ten minutes of the time that the distance of *Mercury* is less than 7′ from the Sun.

Berlin M. T.		Mercury-Sun			Distance of Centers	Equat. Pos. Ang. of Mercury	Distance of Limbs
		$\Delta\alpha$	$\Delta\delta$				
h	m	s					
4	50	+16.12	−23′	6″.9	1406″.3	170°.46	433″.3
5	0	12.49	22	40.9	1372.8	172.45	399.8
	10	8.86		14.8	1341.0	174.52	368.0
	20	5.23	21	48.7	1310.9	176.69	337.9
	30	+1.61		22.6	1282.8	178.96	309.8
	40	−2.02	20	56.5	1256.8	181.33	283.8
	50	5.64		30.4	1233.1	183.79	260.1
6	0	9.27		4.3	1211.7	186.35	238.7
	10	12.90	19	38.2	1192.9	188.99	219.9
	20	16.52		12.1	1176.6	191.71	203.6
	30	20.15	18	46.1	1163.2	194.50	190.2
	40	23.77		20.0	1152.4	197.35	179.4
	50	27.40	17	53.9	1144.6	200.24	171.6
7	0	31.02		27.8	1139.7	203.17	166.7
	10	34.64		1.8	1137.9	206.11	164.9
	20	38.27	16	35.7	1139.1	209.06	166.1
	30	41.89		9.6	1143.2	211.99	170.2
	40	45.51	15	43.5	1150.2	214.89	177.2
	50	49.14		17.4	1160.3	217.75	187.3
8	0	52.76	14	51.4	1173.2	220.55	200.2
	10	56.38		25.3	1188.7	223.29	215.7
	20	60.01	13	59.2	1207.0	225.95	234.0
	30	63.63		33.1	1227.7	228.53	254.7
	40	67.25		7.1	1250.9	231.01	277.9
	50	70.87	12	41.0	1276.3	233.40	303.3
9	0	74.49		14.9	1303.8	235.69	330.8
	10	78.11	11	48.8	1333.3	237.88	360.3
	20	81.73		22.7	1364.7	239.98	391.7
	30	−85.35	−10	56.7	1397.8	241.98	424.8

The solar radius has been taken as $968''.04$ and that of *Mercury* as $4''.97$. Geocentric conjunction occurs at $7^h\ 11^m$, at a distance of $164''.9$ and position angle $206^{\circ}.41$. As the difference in the equatorial horizontal parallax of the two stars amounts to only $4''.17$, it is not necessary to take its effect into account in arranging observations. The only stations for observations are the two halves of the American continent, aside from the Cape, where the event occurs at sunset.

It is quite improbable that the phenomenon will actually be observed, for, in the first place, we must assume prominences of unusual height, the average elevation being hardly over $40''$, and, again, solar activity is at present very slight, although increasing. The above equatorial position angles are reduced to ecliptical by the subtraction of $17^{\circ}.77$, so that *Mercury* will pass not far from the south pole of the Sun, in ecliptical position angle $189^{\circ}.34$. Prominences are only very seldom observed near the poles, although not impossible, and the motion in position angle is rapid, and soon after the closest approach *Mercury*, without moving away very far from there, reaches positions where prominences occur more frequently than at the pole.

It is therefore to be hoped that the regular observers of prominences will especially look out for the region of position angle as situated on November 4. If a prominence of the necessary elevation is situated there, a beginning may be made with the observations, which would be interesting enough. It is regrettable that we are not yet able to observe at any desired time the solar corona, on which *Mercury* would certainly be projected.

F. RISTENPART.

BERLIN, August 14, 1901.

PUBLICATION OF A NEW CATALOGUE OF VARIABLE STARS.

THE council of the *Astronomischen Gesellschaft* has decided upon the publication of a new catalogue of variable stars, and has assigned the work of its preparation to the committee named below.

Observers of variable stars are requested to promptly publish their more extensive, unpublished series of observations, which may be of service in improving the elements, or to communicate regarding them with the executive member of the committee, Professor G. Müller, Kgl. Observatorium, Potsdam, Germany.

The committee also announces that it will from now on assume the assignment of definitive designations to new variables, as soon as their variation is established. A list of the names of the variables discovered in recent years but so far undesignated will be soon published.

THE COMMITTEE:
MESSRS. DUNÉR, HARTWIG, MÜLLER, OUDEMANS.

A CORRECTION.

IN the formulae on page 247 of Volume XI of this JOURNAL, p and q denote the ratios of the *radii* of the two stars to the semi-axis of the orbit. My attention has been called by a friend to the fact that Mr. Roberts has denoted by the same letters the ratios of the *diameters* of the star's semi-axis of the orbit. Consequently the numerical coefficient 0.0092 employed by Mr. Roberts must be acknowledged to be entirely correct.

H. SEELIGER.

MUNICH, July 21, 1901.

CONCERNING THE PAPER "ON THE ABSORPTION SPECTRUM OF CHLORINE."[1]

By ELIZABETH R. LAIRD.

OWING to lack of time, some desired changes could not be made in my paper on the above subject before it went to press, and I would therefore call attention to some explanations and corrections.

In Table I, the same symbol "s" is used in the first column to denote that some of the measurements were made on Sun plates, and in the third to signify sharp. "Band" in Table I, means a line broader than one marked very broad, consisting probably of two or more lines.

The second sentence on page 107 refers to the fact that the fluted appearance is not due to a regular grading in the width or intensity of the lines. The flutings were not observed in the second order spectrum.

In the summary of results, the last three conclusions are based not on the present investigation only, but on a comparison with what seemed to be proper inferences from the work of Hasselberg.

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[1] ASTROPHYSICAL JOURNAL, 14, 85, 1901.

ERRATA.

On page 86, line 15, for "fine" read "five."

On page 87, footnote 4, for "106" read "105."

On page 91, line 10, for "with 0.0007 in." read "width 0.007 in."

On page 92, line 12, for "or" read "and."

On page 92, line 34, for "Ballei" read "Baccei."

On page 96, line 24, column 8, for "3" read "4."

On page 96, line 27, column 4, for ".003" read ".008."

On page 96, line 43, column 6, for "4956.647" read "4856.647."

On page 101, line 18, column 5, for "2" read "3."

On page 102, line 47, column 5, for "3" read "6."

On page 103, line 34, column 6, for "5214.051" read "5215.051."

On page 106, line 11, omit "especially."

On page 107, line 20, for "line of spectrum" read "line spectrum."

On page 109, line 8, for ".So" read ",so."

On page 115, line 4, for "MacKenzie" read "Mackenzie."

SEPTEMBER, 1901.

THE
ASTROPHYSICAL JOURNAL
AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

VOLUME XIV NOVEMBER, 1901 NUMBER 4

THE TWO-FOOT REFLECTING TELESCOPE OF THE YERKES OBSERVATORY.

By G. W. RITCHEY.

THE mounting for the two-foot reflector of the Yerkes Observatory is the largest and perhaps the most important piece of work which has been done in the instrument shop of the Observatory. The telescope is mounted in the southeast dome, which was originally intended for a sixteen-inch refractor. This dome is thirty feet in diameter—somewhat larger than is needed for the reflector, though the protection of the instrument from the wind is better than it would be with a smaller dome. Since the center of motion of the telescope is low it was necessary to extend the original massive brick pier about twelve feet higher in order to bring the instrument sufficiently high with reference to the opening in the dome. A substantial observing platform or floor, twenty feet in diameter and twelve feet higher than the original floor of the tower, was also built. With the present arrangement the eyepiece or plate-holder is never more than eleven feet above the floor, and hence is always easily accessible with the aid of a suitable observing chair.

THE MIRRORS.

While the instrument is generally called the two-foot reflector, the clear aperture of the large mirror is 23½ inches, the focal length being 93 inches. The disk of glass for this mirror was made at the St. Gobain Glass Works, near Paris, for the writer, who finished the work of grinding, polishing, and figuring it, in 1896, at his own laboratory in Chicago. A high degree of accuracy of figure was obtained. Those who have attempted to figure paraboloidal mirrors of large angular aperture will appreciate the care necessary to parabolize accurately a large mirror in which the ratio of focal length to aperture is less than as four to one, as in this case.

In testing this mirror at the center of curvature while figuring it, the writer found that it was entirely unsatisfactory to employ an eyepiece in determining the focus of the successive zones, as described by Draper and Common. The difficulty was due to the great angular aperture and the consequent rapid change of curvature, especially in the outer zones. If zones of the usual width, fifteen or twenty millimeters, were used it was found that the difference of focus of the inner and outer parts of a zone was so great that the image in the eyepiece showed evidence of strong aberration; while if narrow zones, of three or four millimeters width, were used the image in the eyepiece was very indistinct, as a result of the strong diffraction effect produced by the edges of the screen. Finally it was found that very narrow zones or arcs could be used by employing the knife-edge instead of an eyepiece for determining the position of the focus; this method was found to be so accurate that, with some practice, the focus of a zone could be determined without difficulty to within 0.04 mm. Twelve zones were employed in testing, and about three month's work was devoted to the final figuring.

The reliability and accuracy of this method of testing was later demonstrated by independent tests on the stars, with fine atmospheric conditions, and also by testing in conjunction with a 24-inch plane mirror. In the latter test the artificial star is placed at the focus of the paraboloid; the rays of light are collimated by reflection from the paraboloidal mirror, and after reflection from the large plane mirror return to the former mirror in a parallel beam, whence they are reflected to a focus very near to the artifical star. The paraboloidal mirror can thus be tested at its focus, as a whole, without the use of zones, precisely as a spherical mirror is tested at its center of curvature. Given a good plane mirror of the same size as the concave one this method is highly satisfactory in practice; the many tedious focal settings and the somewhat troublesome interpretation of the focal readings, necessary in the zonal test, are avoided; the entire paraboloidal mirror is seen in relief, and the position and character of any errors of figure are most easily determined. The arrangement of mirrors for this test is shown in Fig. 1. In practice the artificial star is placed very slightly to one side of the axis of figure, and the reflected image is formed at the same distance on the opposite side. For convenience a small diagonal plane mirror is also used, as shown in the figure.

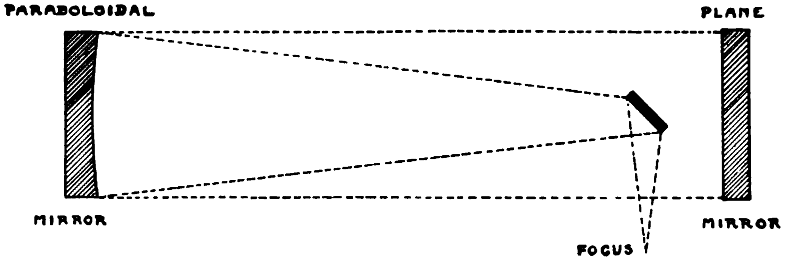


FIG. 1.

In this connection it may be of interest to describe briefly the method of testing used when figuring the five-inch hyperboloidal convex mirror which is employed when this telescope is used as a Cassegrain, and by the use of which an equivalent focal length of 38 feet is secured. The artificial star is now placed at the secondary focus (see Fig. 2); the diverging cone of light strikes the five-inch convex mirror, and is by it rendered more divergent, so that it fills the 23½-inch paraboloidal mirror. The rays are reflected from the latter mirror in a parallel beam, strike the 24-inch plane mirror, return to the concave, then to the small convex and thence to a focus close beside the artificial star. By this arrangement the convex mirror is tested as a whole, at the secondary focus, without the use of zones, precisely as a concave spherical mirror is tested at its center of curvature. Assuming that the large paraboloidal and plane mirrors are finished, any errors of figure which are seen by means of the knife-edge or other tests are due to the convex mirror, and their position and character can be readily determined. The work of grinding and figuring the convex mirror was done, under the writer's direction, by Mr. F. G. Pease, assistant in the optical laboratory.

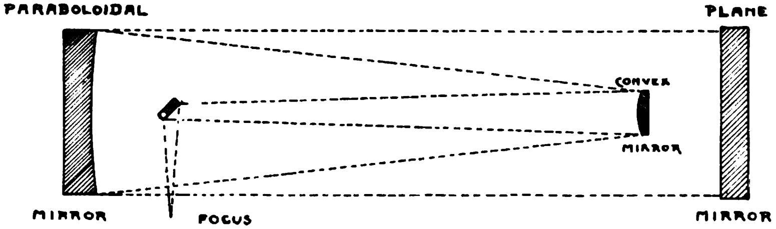
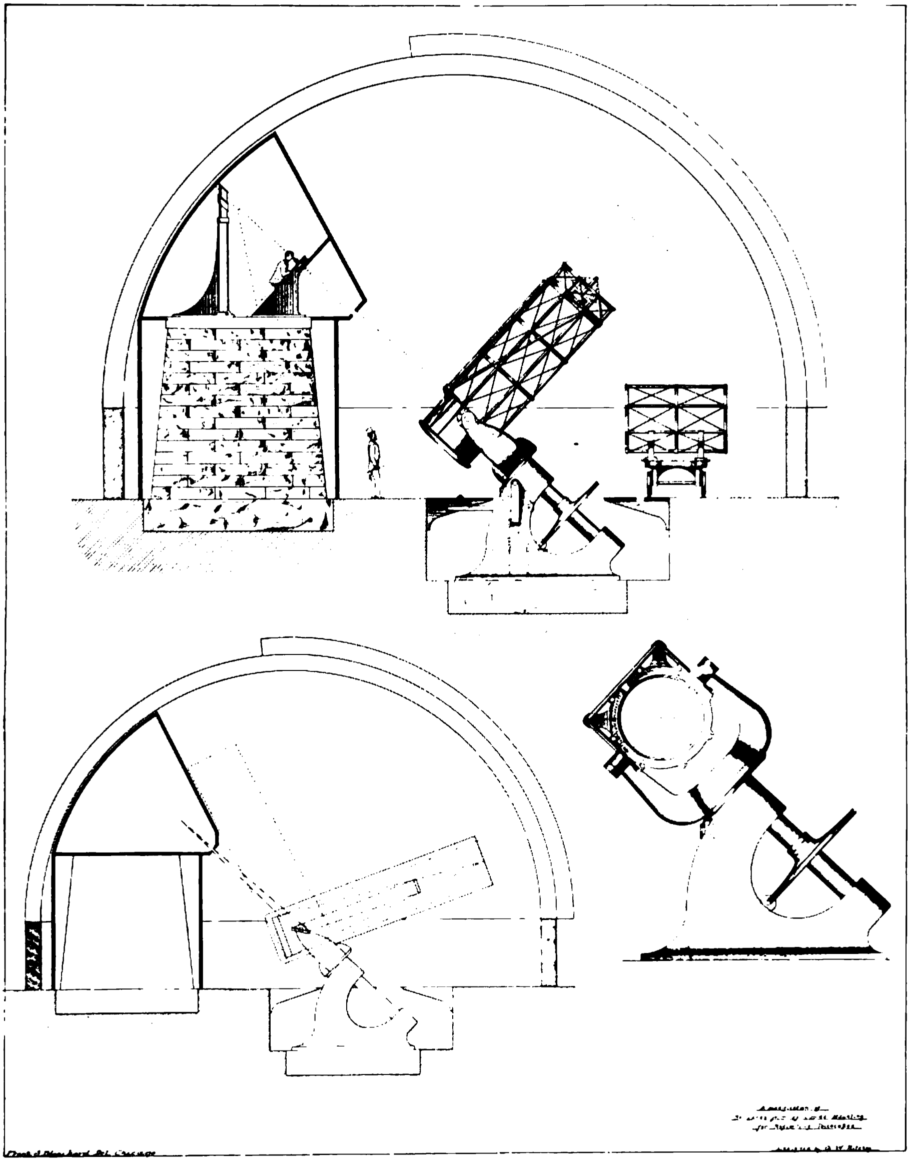


FIG. 2.

THE MOUNTING.

Before describing the mounting a brief historical account may not be out of place. While figuring the large mirror the writer designed a complete mounting for the instrument, in which were embodied the plans suggested by many years of experience with reflecting telescopes and in astronomical photography, and of study of existing mountings. In this design a short massive fork was to be used at the upper end of the polar axis, between the two arms of which fork the tube turned on trunnions for movement in declination. The short strong end of the tube below the declination trunnions contained the large mirror and its cell, which served to balance the skeleton tube above. In this form of mounting no dead-weight in counterpoises is required, and a part of the metal and weight, which in many other forms are necessary for counterpoises, can here be used to advantage

PLATE IX.



DESIGN FOR THE MOUNTING OF A FIVE-FOOT REFLECTING TELESCOPE.

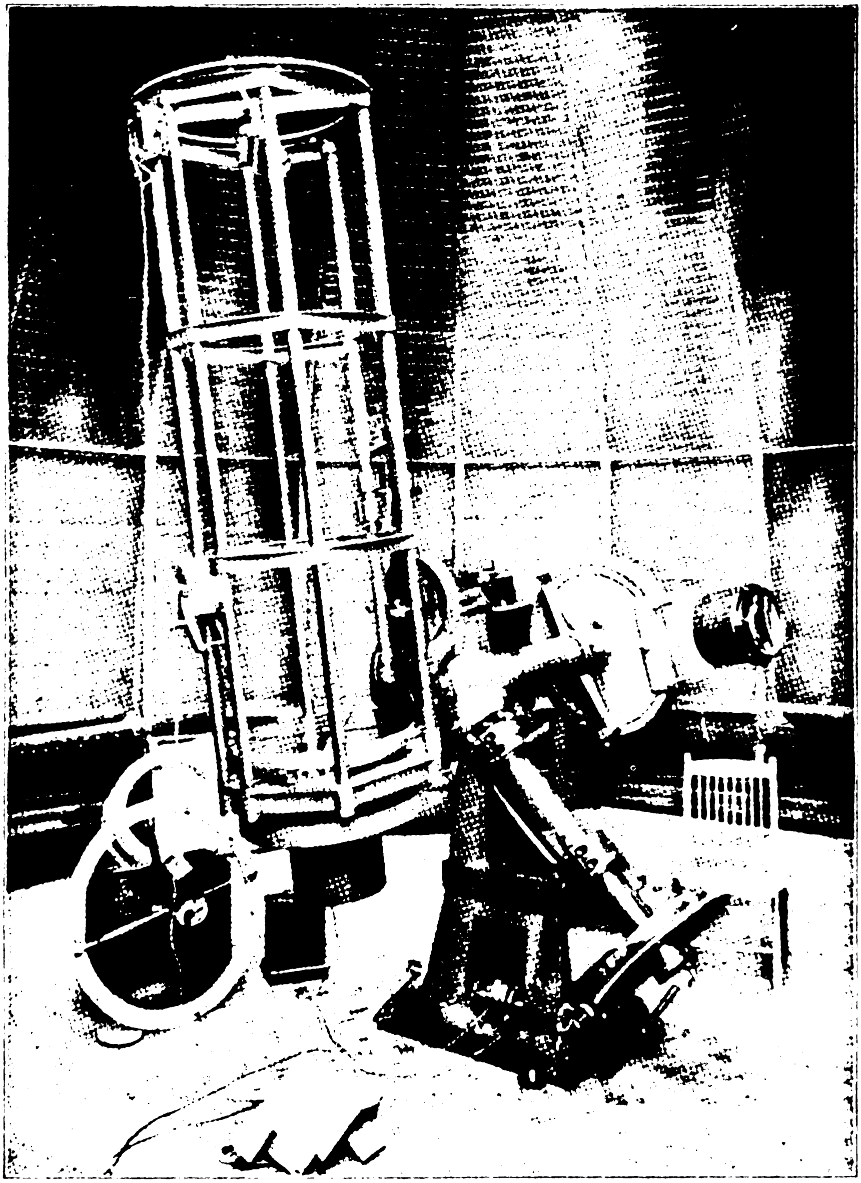
in giving massiveness and extreme rigidity to those parts upon which the stability of the mounting, so necessary in astronomical photography, depends. Included also in this design was the writer's plan of support for the large mirror in its cell (described in this JOURNAL for February, 1897), by which an effective flotation system of support and very great stability of position of the mirror are at once secured. In all essential features, with one exception, the plan of mounting just described is similar to that which the writer has used in designing the mounting for the five-foot reflector, the mirror for which is nearly finished. Several diagrams illustrating the latter design are shown in Plate IX. The exception mentioned is this: The plan for the five-foot is adapted to include, if desired, the *coudè* arrangement of mirrors which was suggested by Mr. Ranyard to Professor Hale in 1894. This arrangement will be readily understood, without description, by reference to the plate.

To return to the subject of the two-foot mounting. For some time after the mirror was finished the instrument shop of the Observatory (which does not include the optical laboratory) was in charge of Professor Wadsworth, who designed a two-foot mounting of very different form, the construction of which was begun under his supervision. When Professor Wadsworth left this Observatory, the writer was placed in charge of the instrument shop, and work on the reflector mounting, which had been long interrupted, was resumed. The heavy base parts, already partially finished, which included the short column, equatorial head, and polar and declination axes, were retained. From the writer's designs the remainder of the mounting was constructed, including the skeleton tube, with interchangeable ends, driving-clock, clock connections, mirror-support, slow-motions, double-slide plate carrier, nine-inch Cassegrain guiding telescope, and the spectroscope support.

As will be seen by reference to Plate X, the arrangement of the axes is similar to that used in the German type of equatorial mounting. The design is such that, while it is possible to reverse the instrument, which is often desirable and convenient, reversal is not necessary, as the end of the tube below the declination axis is so short that it will pass the column without obstruction for all declinations. Long exposure photographs can therefore be started four or five hours east of the meridian, and continued without interruption for eight or ten hours, when desired, as is the case with the fork mounting shown in Plate IX.

On account of the great importance of an effective anti-friction device for the polar axis, attention should be called to the action of the single anti-friction roller used by Professor Wadsworth in this mounting, which is intended to reduce friction at the upper bearing of the polar axis and at the same time to relieve the end-thrust. This plan was originally suggested, I think, by Dr. Gill. The cylindrical roller, with its axis horizontal and its surface slightly crowning, is mounted on a heavily-weighted lever so as to press vertically upward against the conical surface of an enlargement or head at the upper end of the polar axis. This is shown in Plate X. The device is a beautiful one at first sight, but presents serious difficulties in practice. Its action was not smooth and uniform, but gave rise to sharp jerks in driving, which occurred at nearly regular intervals of a few seconds. Part of the trouble was due to the necessary slight slipping of the *cylindrical* roller (though with slightly crowning surface) on the *conical* surface against which it bears; this was shown by the fact that the jumping was improved, but not entirely cured, by turning the surface of the roller much more crowning, so that the line of contact is very short. The manner in which the bearing or axis of the roller is worn indicates that there is also a very strong oblique pressure communicated to the roller by the conical surface; the bad effect of this could be reduced by making the axis or bearing of the roller much longer. The slipping mentioned above could be cured by the use of two conical surfaces having the same angle. A well-made anti-friction end-thrust bearing for the polar axis is most desirable in any case; there is none in the present instrument, and the design of the base parts is such that it would be difficult to introduce one. The trouble in the present case is

PLATE X.



TWO-FOOT REFLECTOR OF THE YERKES OBSERVATORY.

aggravated by the small size of the friction roller and by the great weight of the moving parts; this amounts to about 2,500 pounds, almost exactly one-half of which is due to the counterpoises which, in this particular form of mounting, are necessary on the short lower end of the tube and on the opposite end of the declination axis.

Smooth driving is at present secured by allowing the roller to carry only a small part of the weight of the moving parts, and by attaching sufficient weight to the west side of the mounting to cause the instrument to rotate easily in that direction; unnecessary wear of the clock and the clock connections is thus avoided. This makeshift is, of course, unsatisfactory and somewhat inconvenient in practice; nevertheless good results are obtained.

It must not be supposed that the difficulties just described are at all necessary, or that they are peculiar to the reflecting telescope. On account principally of the very powerful driving clock and clock connections, which are described below, the smoothness of driving of the two-foot reflector, as at present used, is decidedly better than that of the forty-inch refractor; this is best seen when the instrument is used as a Cassegrain, with an equivalent focal length of thirty-eight feet.

THE DRIVING MECHANISM.

The driving-clock, part of which can be seen inside the column in the illustration, is similar in general plan to that of the forty-inch refractor, and is one-fourth the size of the latter, the governor making two revolutions per second instead of one, as in the larger instrument. The governor balls weigh about seven pounds each, and all parts of the clock are proportionally heavy and strong. All of the clock gears were cut in our instrument shop, on the Brown & Sharpe milling machine, by Mr. Johannesen. The winding drum is provided with a maintaining device. Winding is at present done by hand, and must be attended to every two hours.

The connections between the driving-clock and the large worm gear which rotates the polar axis are short and very large and strong; they include a differential gear arrangement for slow motion in right ascension.

The driving-worm and worm gear were ground together for two hundred hours with fine grades of emery (such as are used in optical work) and oil, and the smoothing was finished with polishing rouge and oil. This was done just before the instrument was set up, and with all of the involved parts in their final positions on the mounting. To this the extraordinary smoothness of driving is largely due.

THE MIRROR SUPPORT.

One of the most troublesome difficulties which the writer had to meet in completing the design for the mounting was to find room for an efficient support system for the large mirror.

The writer's original plan of support, referred to above, could not be used on account of the shape of the large casting behind the mirror, which forms a part of the declination axis and which had already been partially finished. The plan of support finally adopted is as follows: The mirror rests upon three very rigid cast-iron plates, ten inches in diameter, the upper surfaces of which are ground to fit the back of the mirror. One thickness of writing-paper is placed between each iron plate and the glass. Each plate is supported at its center on a strong ball-and-socket joint. The three balls form the upper end of the three large adjusting screws which extend through the heavy back casting, and by which the mirror is adjusted for collimation. The edge-support adopted consists of four strong steel bands, each of which is in contact with nearly one-half the circumference of the mirror; two opposite bands are just above the middle of the edge of the mirror; the other two, ninety degrees from the first, are just below this plane. In addition, four long rigid arcs of cast-iron are used to give greater stability of position laterally; two of these are bolted down to the large casting behind the mirror; the other two are held against the edge of the mirror by weak springs.

Although far from perfect in principle, the support system just described is very satisfactory in practice, for a mirror of this size. The mirror is supported without deformation, and no appreciable change of collimation can be detected as the telescope is turned in widely differing positions; this is determined by the use of a modification of Stoney's method of collimation.

THE SKELETON TUBE.

The skeleton tube is about seven feet long, and is constructed of eight two-inch steel tubes, which are connected by three strong light rings of cast aluminum. The rings are driven on the tubes, and each junction is tightly clamped with two strong screws, as can be seen in the illustration. Provision was made for diagonal tension rods, but the frame is so extremely rigid without them that they have not been added.

For various kinds of work three distinct ends or attachments are now used which can be quickly connected to the upper end of the skeleton tube. One attachment consists of a strong cast-aluminum ring which carries, by means of four thin wide bands of steel, the diagonal plane mirror and its supports. This attachment is employed when the telescope is used with the double-slide plate-holder for direct photography at the first focus. A second attachment is a similar ring carrying the convex (Cassegrain) mirror and its supports; this is used when the instrument is employed for spectroscopic work; it will also be used with the double-slide plate-carrier at the secondary focus for the direct photography of objects requiring great scale, and for visual and photometric observations. The third attachment consists of a short light frame which supports a plate-holder at the direct focus of the large mirror, for photographing without the intervention of the diagonal plane mirror; this attachment has been used but little thus far, but can be employed to advantage in direct photographic work for which the double-slide plate-carrier is not available, such as the photography of comets.

For such work a nine-inch guiding telescope has been provided. This is a reflector, of the Cassegrain form, with equivalent focal length of fifteen feet. The advantages of using such a reflector for this purpose are apparent: the heavy parts are all carried by the massive parts of the mounting instead of by the light skeleton tube, and the eyepiece is always in a convenient position for guiding. The nine-inch concave mirror and all of the metal parts for the guiding telescope have been finished, but the 2¾-inch convex mirror has not yet been completely figured; this telescope is, therefore, not attached to the mounting at present, and is not shown in the illustration; it is of course not necessary when the double-slide plate-carrier is used.

THE SPECTROSCOPE SUPPORT.

The method of attaching the spectroscope, which weighs about one hundred pounds, to the telescope mounting will be best understood by reference to Plate X. It is carried by a strong iron ring with two heavy arms, which are bolted to the casting supporting the large mirror and the skeleton tube. The spectroscope is permanently attached to the mounting, and need not be removed to allow other kinds of work to be done with the telescope, as is the case with the spectroscopes which are used with the forty-inch refractor. The suggestion of this very convenient arrangement of the spectroscope is due to Professor Wadsworth.

DOUBLE-SLIDE PLATE-CARRIER.

The double-slide plate-carrier used with the two-foot reflector is the same which was used in the writer's first experiments in photographing with the forty-inch telescope with a color-screen. In the latter work a large sliding plate-carrier taking 8 × 10-inch plates is now used. The smaller one takes 3¼ × 4¼-inch plates, and the field photographed is three inches square, which corresponds, in the two-foot reflector, to a portion of the sky about two degrees square. This invaluable attachment to a photographic telescope was first suggested, I think, by Dr. Common, and is described by him in *Monthly Notices*, **49**, 297. The present instrument or attachment is briefly described by the writer in this JOURNAL, **12**, 355, 1900.[1]

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[1] Plate X shows also a ten-inch portrait lens, temporarily attached to the declination circle.

RESULTS.

In practice the combination of (1) stability of position of mirror; (2) smoothness of clock-driving; (3) rigidity of skeleton tube; and (4) delicacy of following made possible by the use of the sliding plate-carrier, is so effective that when atmospheric conditions are good the image of the guiding star in the eyepiece of the plate-carrier does not wander by so much as one one-hundredth part of a millimeter, during an exposure of three or four hours. The accuracy with which the star images are kept immovable on the photographic plate is nearly as great, as is shown by the photographs. In the best negatives, with four hours' exposure, the images of the smaller stars near the center of the field are about 2″ in diameter. Double stars of 2″.5 distance are sharply separated and those of less than 2″ distance, corresponding to about 0.02 mm on the photographic plate, are measurable. When the focal length is taken into account, these results are not surpassed by those obtained with the best photographic refractors. It is of course only when atmospheric conditions are very fine that such results can be obtained. With such conditions stars fainter than the seventeenth magnitude (the visual limit of the forty-inch refractor), are photographed with forty-five minutes' exposure.

No greater mistake could be made than to suppose that the finest atmospheric conditions are unnecessary to secure the best results in photography of the nebulæ. With such conditions the photographs show that these objects are not diffused hazy masses, but that their structure is most complicated, often consisting of exquisitely fine filaments and delicate narrow rifts. In these photographs the intersections of such filaments and rifts can be set upon in the measuring machine with almost the same accuracy that is possible in the case of star images. Changes of form of the nebulæ, if such occur, could be detected with certainty by such photographs. There can be no question in regard to the superiority of the photographic method over the visual for the detection of such changes, and for the study of nebulæ in general. The greater part of the fine structure referred to cannot be seen directly with any telescope; this is due partly to the fact that it is usually too faint to affect the eye, and partly to the fact that in the photographs the contrast between light and dark parts can be greatly exaggerated by proper development.

Plate VIII is from a photograph of the Great Nebula in *Andromeda*, obtained by the writer with the two-foot reflector on the night of September 18, 1901, with an exposure of four hours. The aperture was in this case reduced to eighteen inches, in order that good definition might be secured over a larger field than is well covered when the full aperture is used. In the original negative the fine spiral structure is visible almost to the center of the nebula, and the stellar nucleus is distinctly seen. Sharply defined narrow rifts and dark holes are shown on all of the negatives near the center; no trace of these can be detected visually with any telescope. The enlargement as compared with the original negative is 4.5 diameters.

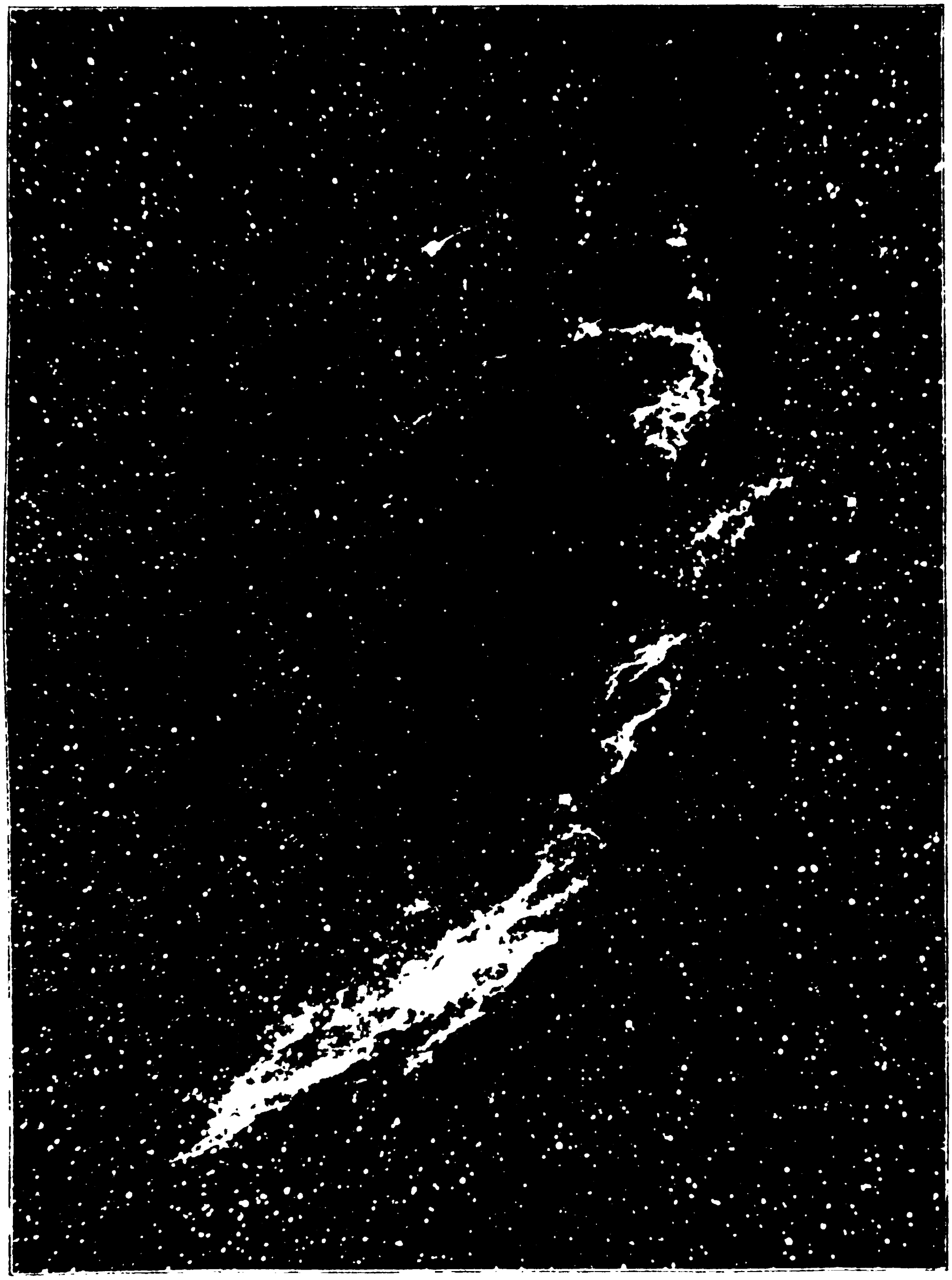
The photograph of the nebula *N. G. C.* 6992 in *Cygnus* (Plate XI) was taken on the night of October 5, 1901, with an exposure of three hours. The enlargement from the original negative is in this case about 3.5 diameters. Some idea of the wonderful filamentous structure of this nebula can be obtained from the half-tone illustration, but, as in the case of the illustration of the *Andromeda* nebula, an enlargement fully four times as great would be necessary in order that the fine details shown on the negative might be satisfactorily reproduced in the half-tone plate. In making these photographs the most rapid plates obtainable are used, and the granularity of the negatives is kept extremely fine by careful treatment in development.

CONCLUSIONS.

The experience gained in the construction and use of this instrument, and the results obtained with it, are most interesting to the writer as showing the possibilities of the future great reflector in astronomical photography. It has often been asserted by prominent writers on the subject that a large reflector

PLATE XI.

S.



N.

NEBULA *N. G. C.* 6992, IN *CYGNUS.*

Photographed with the Two-Foot Reflector of the Yerkes Observatory by G. W. Ritchey.

is necessarily inferior to a large refractor in many vital points, such as permanence of optical qualities, freedom from injurious flexure of optical parts, permanence of adjustments or collimation of optical parts, rigidity and stability of the mounting, and convenience in use. Unfortunately for astronomical science the experience with many of the large reflecting telescopes which have been built has been such as to give apparent support to this view. Even the experience of the late Professor Keeler with the Crossley reflector, with which, in spite of the great difficulties described by him, he obtained such superb results, was such that one might easily suppose these difficulties to be unavoidable in a great reflector.

Nothing could be further from the truth. A large mirror can without difficulty be mounted in its cell with all of the stability of position possible in the case of a large lens, and with far greater stability of position than is now attained with such lenses. While the effect of flexure is more serious in the case of a large mirror than in that of a lens, such a mirror can be made very thick (this is objectionable in the case of a lens on account of greater absorption), and can be supported at its back by a flotation system inexpensive in construction and of any required degree of efficiency; twelve supporting plates or any larger number can be used, each of which carries its own proportion of the weight of the glass. Such a support in no way interferes with the stability of position of the mirror, above referred to.

With reference to permanence of optical qualities, permanence of adjustments, difficulty of silvering, etc., it should be stated that the re-silvering of large mirrors is not at present a difficult operation. While the shape of the heavy casting behind the large mirror in the two-foot reflector is such that the mirror can be removed from the mounting for re-silvering only by lifting it out through the sides or end of the skeleton tube, yet this mirror and the diagonal flat have been removed from the mounting, re-silvered, burnished and replaced without sensibly disturbing the adjustments and collimation, as shown by very sensitive tests, and without changing the position of the focal plane by so much as 0.05 mm, the interval which is used in making the trial photographs for focus. Three or four hours are required for the entire operation, including the preparation of the silvering solutions. In the form of reflector mounting shown in Plate IX the large mirror can be removed from the telescope with ease and quickness, and without removing it from its cell or its supports it can be re-silvered and replaced in the telescope without the slightest appreciable disturbance of adjustments, collimation, etc. With a five-foot mirror this could be done in eight or ten hours — between morning and evening of any day.

With reference to permanence of focal length the following facts may be stated. In making trial photographs for focus of the two-foot reflector it is found that the position of the focus can be determined to within 0.05 mm, when atmospheric conditions are good. A careful record of the focal length of the mirror for a range of temperature of about 28° C. has been kept. The apparent differences of focus at the plate-holder on different nights are found to be such as are exactly accounted for, in direction and amount, by the expansion and contraction of the steel tubes of the skeleton framework, following temperature changes. Since the change in the length of the steel framework for the range of temperature mentioned is about 0.75mm and the focus determinations are accurate to within 0.05mm, it is certain that the actual change in the focal length of the mirror for this range of temperature is so small that it cannot be detected.

No changes of focus during long exposures, such as are described by Professor Keeler in the case of the Crossley reflector, and which he attributes to the effect of flexure in the instrument, can be detected in the two-foot reflector, though they have been carefully watched for.

In the case of the forty-inch refractor, the absolute focal length of the objective is shortened by a given fall of temperature, by an amount almost exactly twice that of the contraction of the tube. Thus, for a fall of 28° C. the focal length of the objective is shortened by about 12 mm, while the contraction of the tube amounts to 6.25 mm. The accuracy with which, with the best atmospheric conditions, the focus of the forty-inch refractor can be determined by trial photographs for focus, is about one-fifth as great as in the case of the two-foot reflector. This is in good accord with the ratio of the angular apertures of the two instruments.

With regard to the question of the rigidity and stability of the mounting of a reflecting telescope, it will be seen, by again referring to Plate IX, that all of the heavy parts of such a mounting, including the parts which carry the large mirror, can be made extremely compact, massive, and rigid. The skeleton tube also can be made excessively rigid; it is very short as compared with the tube of a refractor of the same aperture; and it has no great weight to carry at its extremity, as is necessary in the case of the refractor. How unreasonable then is the common assertion that the reflector mounting is necessarily clumsy, unstable, and subject to large flexures.

The following considerations may serve to illustrate the convenience and economy of the reflector.

One of the most important points to be decided in undertaking the construction of a reflecting telescope for photographic work is in regard to the ratio of focal length to aperture to be adopted. As already stated, this ratio in the case of the two-foot reflector is nearly as four to one. With such a ratio the light-concentration is very great, and faint nebulæ can be photographed with proportionally short exposures. The advantages of such a large angular aperture are strikingly shown in the photography of such objects as the excessively faint nebula about *Nova Persei*,[1] and in photographing the faint spiral nebulae, the great majority of which are small. But the field which is sharply covered when this angular aperture is used is necessarily small. In photographing such large objects as the *Andromeda* nebula and the *Pleiades*, the aperture of this telescope is usually reduced to twenty or eighteen inches; the field which

[1] ASTROPHYSICAL JOURNAL, 14, 167, 1901.

is well covered is thereby much increased in size, while the necessary exposures are of course lengthened. In the five-foot reflector, a ratio of five to one was adopted.

Experience in figuring and testing rigorously the convex mirror for the two-foot, as described earlier in this article, and its actual use in the telescope, have led to the belief that the enlarged images obtained by the addition of the Cassegrain mirror are nearly or quite as perfect as can be obtained by the direct use of a large mirror of great focal length. Taking the five-foot reflector of twenty-five feet focal length as an illustration, it will be possible to use this great instrument at its principal focus for the photography of such objects as the large and faint nebulæ, and, by the addition of a convex mirror of about eighteen inches diameter, amplifying three or four times, an equivalent focal length of seventy-five or one hundred feet can be secured, for the photography of objects requiring great scale, such as the dense star clusters and annular and planetary nebulæ. For all kinds of work perfect achromatism and the high photographic efficiency of the reflector are retained. The skeleton tube in this instrument will be a little over six feet in diameter, and its length will not be greater than eighteen feet for any of the work mentioned. The internal diameter of the dome need not be greater than forty-five feet.

But however perfect the mirrors, and however carefully designed the mounting of the future great reflector, no improvement in the results in any degree proportional to the increase of size can be expected without a fine climate, with good atmospheric conditions, in which to use it.

The results obtained with the two-foot reflector show that very fine atmospheric conditions are necessary for the best results even in the photography of nebulæ, while for the photography of such objects as the dense globular star clusters the requirements are, if possible, even more exacting. It is interesting to think of the photographic results which could be obtained with a properly mounted great reflector in such a climate and in such atmospheric conditions as prevail in easily accessible parts of our own country, notably in California.

I wish to express my indebtedness to Professor Hale and Mr. Ellerman for valuable suggestions: to Mr. Johannesen, the Observatory instrument maker, and to Mr. Neidhold, the former machinist, for the excellent workmanship of the mounting of the two-foot reflector; and to Mr. Pease for most able and enthusiastic assistance in nearly all of the direct photographic work with the instrument.

YERKES OBSERVATORY,
UNIVERSITY OF CHICAGO.
October 25, 1901.

ON THE TEMPERATURE AND COMPOSITION OF THE ATMOSPHERES OF THE PLANETS AND THE SUN.[1]

By E. ROGOVSKY.

IT is shown in aerostatics that the density ρ_r of any gas at the distance r from the center of the Earth, or other solid or liquid body surrounded by a gaseous atmosphere, may be expressed as follows :

$$\rho_r = \rho e^{-\frac{ag}{k}\left(1-\frac{a}{r}\right)} \tag{1}$$

where ρ is the density of this gas at the surface of the body in question—for instance, the Earth ; e is the base of the Naperian logarithms, a is the radius of the body, g is the acceleration due to the attraction at its surface, k is the coefficient in the formula

$$p = k\rho \tag{2}$$

where p is the pressure of the gas. This coefficient, it is known, depends on the temperature, and $k = k_0(1+\alpha t)$, where t is the temperature of the gas, k_0 the value of k at $t = 0°$, and α the coefficient of thermal expansion of gas, or $k = \alpha k_0 T$, where T is the absolute temperature $= t + 273°$. The kinetic theory of gases gives a formula identical with (1),[2] but $k = \frac{V^2}{3}$, where V^2 is the mean of the squares of the velocities of all the molecules of a given gas.

As we know, gases may expand infinitely. This follows from experiments, the results of which may be expressed by Boyle's formula, or that of van der Waals or Clausius, and it is also a necessary consequence of Maxwell's kinetic theory of gases,[1] which assumes that the molecules of gases have all possible, and, consequently, very high, velocities. The atmospheres of the planets and Sun are, therefore, unlimited, and pass gradually into the cosmical or interplanetary medium.

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[1] Revised and translated by the author from *Transactions of the Russian Astronomical Society*, Part VII, 1898, pp. 10–34, and VIII, 1899, pp. 32–45.

[2] E. ROGOVSKY, "On the Constitution of the Earth's Atmosphere and General Laws of the Theory of Gases," *Journ. of Russ. Phys.-Chem. Soc.*, **16**, 32, 1884.

Putting in (1) $r=\infty$, we find

$$\rho_\infty = \rho e^{-\frac{ag}{k}}\,, \tag{3}$$

i. e., the partial density of the given gas in this medium. According to the kinetic theory of gases, this medium is composed of molecules moving in orbits having the form of a parabola or hyperbola.[2]

Taking another body, the density of the same gas in the interplanetary medium will be found

$$\rho_\infty = \rho_1 e^{-\frac{a_1 g_1}{k_1}}\,. \tag{4}$$

The quantities (3) and (4), being the density of the same gas in the same medium, are equal to each other, and, consequently, when both atmospheres are in equilibrium,

$$\rho e^{-\frac{ag}{k}} = \rho_1 e^{-\frac{a_1 g_1}{k_1}}\,, \tag{5}$$

or

$$\frac{a_1 g_1}{k_1} - \frac{ag}{k} = \log \rho_1 - \log \rho. \tag{6}$$

The temperature of the celestial medium or space has no sensible influence on the distribution of the gases among the atmospheres of the Sun and planets:[3] its increase or decrease causes only the equal expansion or contraction of all the atmospheres without affecting their relative density. The distribution of gases and the relative density of the atmospheres upon the planets depend only on their own internal heat and that produced by the Sun's radiation. The sum of these two is the amount by which the temperature of the atmospheres of the planets exceeds that of the interplanetary or celestial medium, and, therefore, instead of k and k_1 in the foregoing formula, we may write ak_0T and ak_0T_1, if T and T_1 are the differences between the mean temperatures of the atmospheres of the bodies and the temperature of the celestial space or medium. We have

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[1] J. C. MAXWELL, "Illustration of the Dynamical Theory of Gases," *Phil. Mag.*, 4th ser., 19, 19–32, 1860; 35, 129–145, 185–217, 1868. See also, for instance, O. E. MEYER, *Die kinetische Theorie der Gase*, 2. Aufl. 1897–1899 (an English translation exists); L. BOLTZMANN, *Vorlesungen über Gastheorie*, I Th. 1895, II Th. 1898; H. W. WATSON, *A Treatise on the Kinetic Theory of Gases*, 1893; S. H. BURBURY, *A Treatise on the Kinetic Theory of Gases*, 1899: or any course on thermodynamics, for instance, those of RÜHLMANN, CLAUSIUS, KIRCHHOFF, etc.

[2] E. ROGOVSKY, *loc. cit.*, pp. 35, 534. In this paper the number of both kinds of molecules is determined.

[3] The distribution of the gases among the planets is also not affected by their mutual attraction and their movements, owing to their very great mutual distances in comparison with the size of those parts of their atmospheres which have a perceptible density.

$$\frac{a_1 g_1}{T_1} - \frac{ag}{T} = \alpha k_0 (\log \rho_1 - \log \rho), \tag{7}$$

or

$$\frac{a_1 g_1 T}{ag T_1} - 1 = \frac{\alpha k_0 T}{ag} (\log \rho_1 - \log \rho). \tag{8}$$

Attributing the letters without the subscript to the Earth, $\frac{\alpha k_0 T}{ag}$ is about 0.00031; assuming, moreover, $\log \frac{\rho_1}{\rho}$ to be small, which is admissible on account of the small difference of the densities of the Sun and planets (see Table II), the second member of equation (8) may be neglected.

Thus, we have

$$\frac{T_1}{T} = \frac{a_1 g_1}{ag}, \tag{9}$$

or $\frac{ag}{T}$ is constant for all the planets.

We can give to formula (9) a simpler form, since

$$g = f\frac{m}{a^2} \text{ and } g_1 = f\frac{m_1}{a_1^2}$$

where m and m_1 are the masses of two bodies, and f is the constant of gravitation.

Thus,

$$\frac{T_1}{T} = \frac{\frac{m_1}{a_1}}{\frac{m}{a}}$$

or $$\frac{T_1}{T} = \frac{U_1}{U},[1]$$

U and U_1 expressing the values of the potential function of gravitation at the surfaces of the bodies T and T_1, the differences between the mean temperatures of their atmospheres and that of the celestial medium. But it is evident that they also represent the differences between the mean temperatures at the surface of the bodies and that of the celestial medium or space.

The density of the interplanetary medium is given in formula (3). It is clear, the greater $k = \frac{V^2}{3}$, *i. e.*, the greater the velocity of the molecules of the gas, or, in other words, the smaller its atomic weight, the more slowly its density changes in the neighborhood of the celestial body; consequently the heavier gases are more condensed at the surface of the bodies; on the contrary, in the interplanetary medium the lighter gases are found in larger quantity. Putting the density of the air at the Earth's surface as unity, and the mean absolute temperature of its atmosphere as $209^\circ.5$ ($= -63^\circ.5$ C.),[2] the density of air considered as simple substance in the celestial medium is about 10^{-450}, that of oxygen separately, 10^{-500}, of nitrogen, 10^{-440}. The ratio of the last two equals 10^{-60}. These densities are so small that the medium can have no influence on the motion of the heavenly bodies.

Since the molecules of this medium are in motion, it has a certain temperature, and by the "temperature of celestial space" must be understood that of the medium which fills this space. The atmospheres of the planets, therefore, being composed of the molecules of this medium, also possess its temperature; but, besides that, there are yet other sources of heat; because every planet has its own internal heat, and also receives heat from the Sun by radiation. According to the theory of Kant and

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[1] E. ROGOVSKY, "On the Temperature of the Celestial Bodies," *Journ. of the Russ. Phys.-Chem. Soc.*, 17, 314–325, 1885; *Fortschr. d. Physik*, 41, 3. Abth., 1577, 1885; *Beiblätter zu Wiedemann's Ann. d. Phys. und Chem.*, 11,64, 1885. The formulae are the same, but the numerical results there given are not admissible.

[2] See p. 240.

Laplace, the celestial bodies themselves may be regarded as having been produced by the condensation of the celestial medium. But every condensation of matter develops heat, and it is the cause of the internal heat of the celestial bodies. Being expended by degrees through radiation, this heat, nevertheless, exists at the present time within them, as is shown, not only by the high temperature of the Sun and stars, but also by the heat of the central mass of the Earth. In the first stages of the evolution of the body which is in a state of gas, the heat produced by condensation is greater than that lost by radiation, as shown by A. Ritter,[1] and, therefore, its temperature gradually increases; but when a part of its substance passes to the liquid or solid state, *i. e.*, forms a liquid or solid nucleus, the quantity of heat developed by contraction of this nucleus and its gaseous atmosphere may become less than that lost by radiation, because the radiation of solid and liquid bodies at the same temperature is greater than that of gaseous bodies.[2] Accordingly, the celestial body then begins to cool. We cannot say in what stage of development the Sun is at the present time,[3] but the Earth and planets are in that of cooling. Some part of this heat, as has been said, is, nevertheless, still retained by the Earth as well as by the planets, and may be called their "own heat," and, as we shall see, can be of very great amount on the large planets, *Jupiter*, *Saturn*, and others.[1] This heat is retained principally in their nuclei, and the atmospheres of the planets receive it from them.

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[1] A. RITTER, "Untersuchungen über die Höhe der Atmosphäre und die Constitution gasförmiger Weltkörper," *Wied. Ann.*, **5**, 554, 1878. See also ASTROPHYSICAL JOURNAL, **8**, 293, 1898.

[2] F. ROSSETTI, see p. 246.

[3] If we suppose that the temperature of the Sun at the present time is still increasing, or, at least, has been increasing until now, the glacial period of the Earth may be easily accounted for. Formerly, the Earth had a high temperature of its own, but received a lesser quantity of heat from the Sun than now: its climate was then warmer and more uniform than at present; on cooling gradually, the Earth's surface attained such a temperature as caused a great part of the surface of its northern and southern hemispheres to be covered with ice; but the Sun's radiation increasing, the glaciers melted, and the climatic conditions became as they are now. In a word, the temperature of the Earth's surface is a function of two quantities: one decreasing (the Earth's own heat), and the other increasing (the Sun's radiation), and, consequently, there may be a minimum, and this minimum was the glacial period, which, as shown by recent investigations, for instance, those of Luigi de Marchi (Report of G. SCHIAPARELLI, *Meteorolog. Zeitschr.*, **30**, 130–136, 1895) was not local, but general for the whole Earth. (See also M. NEUMAYR, *Erdgeschichte.*)

The other part of the heat of the atmospheres of the planets is received from the Sun.

Thus, their temperature has had three sources, and is, as it were, composed of three temperatures: that of the celestial medium, that produced by their condensation (their own heat), and, lastly, that produced by solar radiation.

Pouillet found, by means of his actinometric measurements, that the temperature of the celestial, or interplanetary, medium is 142° C. below zero (from —175° to —115° C.)[2] The source of this heat he ascribes to the radiation of the stars. Such a supposition is, no doubt, erroneous, for the ratio of the heat emitted by the stars to that emitted by the Sun must be of the same order as the ratio of their light, *i. e.*, very small. But the faultiness of the supposition does not affect his measurements. We assume that the radiation of the heavens in Pouillet's measurements is emitted by the upper strata of our atmosphere, identified by us with the celestial medium, and —142° C. is the temperature of this medium. The assumption that its temperature is absolute zero is groundless: it is inadmissible that the molecules of the gases of the interplanetary medium should be motionless. Later experiments by Froelich completely confirmed Pouillet's results, viz., he found that the temperature of celestial space was —131° on August 17, and —127° on September 23.[3] Consequently, we assume that the temperature of celestial space is −142° C., according to Pouillet, although, perhaps, Pouillet's calculations must be revised and harmonized with Stefan's law; but the correction will principally affect the Sun's temperature; that of celestial space cannot be appreciably modified by it.

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[1] See pp. 247–249, below.

[2] POUILLET, "Mémoire sur la chaleur solaire, sur les pouvoirs rayonnants et absorbants de l'air atmosphérique, et sur la température de l'espace," *Comptes Rendus*, 7, 24–65, 1838.

[3] O. FRÖHLICH, Ueber Himmelswärme, etc.," *Pogg. Ann. Ergänzungs.* **8**, 664–669, 1878. On the other hand, Professor D. Mendelejeff found from the observations of Glaisher that the temperature of the upper strata of the Earth's atmosphere is about —36° C. (D. MENDELEJEFF, *Journ. of the Russ. Phys.-Chem. Soc.*, 7, 260–265, 1875); but recent ascents of free balloons refute it; much lower temperatures were observed, for

The mean temperature of the surface of the Earth may be assumed to be +15° C.,[1] and, thus, the mean temperature of the Earth's atmosphere is $\frac{-142+15}{2} = -63^{\circ}.5$ C., *i. e.*, 78°.5 C. above that of celestial space. Multiplying this number according to formula (10) by the ratio $\frac{U_1}{U}$ of the potential functions of gravitation at the surfaces of the body in question and the Earth given in the second column of the following table, and adding to the results −142°, *i. e.*, the temperature of the celestial medium, we can easily obtain the mean temperatures of the atmospheres of all the bodies of the solar system. These temperatures (θ_1)

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instance, on the aerostat which was started from Paris on February 18, 1897, the temperature −66° C. was registered at 15,000m, and on that from St. Petersburg, even −75° C. at 11,000 meters. Ekholm, from the ascents of balloons, finds that the temperature at the height of 347,000m must be equal to absolute zero (−273° C.). (EKHOLM, *Meteorol. Zeitschr.* **31**, 480, 1896; *Wildermann's Jahrb. der Naturwissensch.*, **12**, 262, 1897), but we have seen that this is impossible. Recently Guillaume ("La température de l'espace," *La Nature*, **24**, Series 2, 210–211, 234, 1896) assuming that the temperature of celestial space is that of a perfectly black ball of very small size placed in this space, concludes that the temperature at an infinite distance from the Sun should be −267°.4 C. The absolute temperature, according to Stefan's law, should be inversely proportional to the square root of the distance from the Sun, and should be, at the distance of

Mercury	+156° C.	*Jupiter*	− 49° C.
Venus	+ 94	*Saturn*	− 80
Earth	+ 65	*Uranus*	−102
Mars	+ 32	*Neptune*	−132

the effective temperature of the Sun being +6,000° C. But it is not possible that the temperature at the boundary of the Earth's atmosphere should be +65° C., and consequently, these figures cannot express the actual temperature in celestial space—especially since they are based on the hypothesis that the celestial medium has no heat of its own.

[1] Dove found on the average +11°.7 R. = 14°.6 C. (E. E. SCHMID, *Lehrbuch der Meteorologie*, 1869, p. 408); Forbes, +15°.6, and Spitaler, +15°.1 C. (W. PRECHT, "Neue Normaltemperaturen," *Meteorol. Zeitschr.*, **29**, 81–90, 1894.

are given in column 3 of the table. The mean temperatures of the surfaces of the same bodies (t_1) are given in column 7; they have been obtained by adding 142° to twice the figures of column 3. I would point out that in both these columns the complete temperatures of the planets are given, *i.e.*, taking into consideration heating by the Sun.

But the Sun's radiation chiefly affects the lower strata of the planetary atmospheres, as is proved by the more rapid increase of temperature on approaching the Earth's surface.[1] On this account, the mean temperature of the Earth's atmosphere found above is too high, and, therefore, the mean temperatures (θ_1) of the atmospheres of the planets given in the third column of the table are also higher than occurs in reality ; they are, indeed, the highest limit of these temperatures. On the contrary, if we entirely neglect the influence of solar radiation, we shall find these temperatures to be below the true values. According to Pouillet, if the surface of the Earth were not heated by the Sun, its temperature would be —89° C.[2] This value, in all probability, is near to the truth, for a temperature of $-69^\circ\!.8$ C. has been observed in the polar regions (in Verkhoiansk, in Siberia[3]). The temperature of the Earth's surface in the polar regions certainly cannot fall to —89° C., owing to the air currents from the warmer regions. Hence, the mean temperature of the Earth's surface not heated by the Sun would be $\frac{-89-142}{2}$ $= 115^\circ\!.5$ C., *i. e.*, $26^\circ\!.5$ higher than the temperature of celestial space (-142° C.). Multiplying this difference by the ratio of the potential functions $\frac{U_1}{U}$, we obtain the minimum differences between the mean temperatures of the atmospheres of the planets and that of the celestial medium ; adding to the differences -142°, we get the minimum of the mean temperatures (θ_2) of the atmospheres of the planets and the Sun. The figures in column 5 of the table are the means of the two foregoing quantities.

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[1] A. SPRUNG, *Lehrbuch der Meteorologie*, 1885, pp. 84–86.

[2] POUILLET, *loc. cit.* pp. 24–98.

[3] HANN, *Meteorol. Zeitschr.* 31, 242, 1896 ; *Wildermann's Jahrbuch d. Naturwiss. für 1896–7*, 12, 302.

In order to find the temperatures of the surfaces of the planets, not only must 142° be added to twice the numbers of column 4, but also the rise in temperature produced by the Sun's radiation. The latter raises the mean temperature of the Earth's surface from − 89° C. to + 15° C., *i. e.*, by 104°. We may, moreover, assume that only an inconsiderable quantity of heat passes from their nuclei into the atmospheres in case of the Earth and planets smaller than it, as the Moon, *Mercury*, *Venus*, and *Mars*. Then, using Stefan's law, according to which the radiation of a body varies directly as the fourth power of its absolute temperature, and supposing that the surfaces of the bodies are perfectly black, we may write

$$\frac{S}{4\pi R^2} T^4 = (t + \tau)^4 - 131^4 \qquad (11)$$

where $\frac{S}{4\pi R^2}$ represents the ratio of the apparent surface of the Sun seen from the body to the surface of the whole heavens, T the absolute temperature of the Sun's surface, t the absolute temperature of the surface of the body not heated by the Sun's radiation, τ the rise of temperature produced by that radiation, 131 the absolute temperature of the celestial space or medium. The first part of the equation is proportional to the radiation of the Sun, and the second to the difference between the radiation of the body and that of the surrounding celestial medium. Assuming the mean temperature $t + \tau$ of the surface of the Earth to be 288° (+ 15° C.), we shall find the "effective" temperature T of the Sun's surface (*i. e.*, its temperature if blackened) to be 5900° C.; substituting, moreover, in equation (11) the temperatures t_1 of the surfaces of the planets not heated by the Sun, placed in column 7 of Table II and calculated as I have just stated, we shall obtain the following values of τ: *Mercury* 320°, *Venus* 165°, the Earth and Moon 104°, *Mars* 96°. No doubt these numbers may differ very much from the true values, because of the presence upon these planets of atmospheres having other densities and heights than that of the Earth.[1] Adding these numbers to the temperatures of the bodies which we have found above, we shall get the temperatures t_2 of the surfaces of the planets given in column 8 of the table.

In the case of the great planets, *Jupiter*, *Saturn*, *Uranus*, and *Neptune*, a term must be introduced expressing the quantity of heat which passes into their atmospheres from hot nuclei. As it is unknown, we cannot exactly calculate their heating due to the Sun's radiation, but on account of its smallness, we may assume it to be inversely proportional to the square root of the distance of those planets from the Sun[2]; then we shall find for

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[1] How the presence of an atmosphere influences the temperature of the Earth's surface or that of the planets has not yet been explained. Supposing the atmosphere to be more transparent for the visible rays than for the invisible (infra-red), it is ordinarily assumed that its presence increases the mean temperature of the Earth. Thus, according to Pouillet, the mean temperature of the surface of the Earth without the atmosphere would be — 55° C. instead of + 15° C. (D. A. LATCHINOFF, *Meteorology and Climatology* (in Russian). St. Petersburg: p. 35), and according to Froelich — 39° C. (*id.* p. 36). But Müller, Abney (J. SCHEINER, *Strahlung und Temperatur der Sonne*. Leipzig, 1899, p. 9), and Langley's measurements (S. P. LANGLEY. "The Selective Absorption of Solar Energy," *Phil. Mag.* (5), 15, 153–183, 1883; see *loc. cit.* 165), proved that red and infra-red rays are, on the contrary, more absorbed by the Earth's atmosphere. This may change our opinion that the atmosphere preserves from cooling. Nevertheless, Langley inferred that the mean temperature of the Earth's surface deprived of the atmosphere would be — 220° C. (W. TRABERT, "Das solare Klima," *Meteorol. Zeitschr.*, 1894, p. 425–427.) On the contrary, Trabert (*loc. cit.*) found this temperature to be $+35^\circ.6$ C. (between — 273° C. in the polar regions in winter, and + 67° C. in the tropical regions in summer).

[2] This law was given by Christiansen (C. CHRISTIANSEN, "Nogle Bemaerkninger angaaende Planeternes Varmegrad." *Oversigt over det Kong. Danske Videnskabernes Selskabs Forhandlinger*, 1885. Kiobenhavn; see also GUILLAUME, *loc. cit.*). This was inferred from Stefan's law, assuming the celestial bodies to have no proper heat and the absolute temperature of celestial space to be zero; it may be deduced from the formula (11) by suppressing 134° and t. Using this law and Zöllner's numerical values of the albedo of the planets, Christiansen has given the following temperatures of the planets:

Name of Planet.	t	t'	Name of Planet.	t	t'
Mercury	210° C.	189° C.	*Jupiter*	−150 C.	−147° C.
Venus	57	65	*Saturn*	−180	−180
Earth	15	15	*Uranus*	−209	−207
Mars	−34	−40	*Neptune*	−221	−221

t is the surface temperature of the planet calculated from its albedo, and t' by Stefan's law.

Jupiter 46°, *Saturn* 34°, *Uranus* 24°, and *Neptune* 19°. All these values are placed in column 6 of the table.

Adding these figures to the surface temperatures of the bodies (without the effect of the Sun's radiation) calculated as above, we shall obtain the figures t_2 in column 8.

TABLE I.[1]

Name of Body.	$\frac{U_1}{U}$	Mean Temperature of the Atmosphere.			Surface Heating by the Sun's Radiation.	Mean Temperature of the Surface.		
		θ_1	θ_2	Mean θ		t_1	t_2	Mean t
1	2	3	4	5	6	7	8	9
Sun	2998.4	(+235000° C.	+79000° C.	+157000° C.	....	+470000° C.	+158000° C.	+314000° C.)
Mercury	0.16375	− 129	− 138	− 133	320° C.	− 116	+ 196	+ 40
Venus	0.8012	− 79	− 121	− 100	165	− 16	+ 65	+ 25
Earth	1	− 635	− 115.5	− 89.5	104	+ 15	+ 15	+ 15
Moon	0.04750	− 138	− 141	− 140	104	− 134	− 36	− 85
Mars	0.19855	− 126	− 137	− 131	96	− 110	− 36	− 73
Jupiter	26.738	+1960	+ 565	+1260	46	+4060	+1320	+2690
Saturn	9.0814	+ 570	+ 99	+ 335	34	+1280	+ 374	+ 827
Uranus	3.0337	+ 96	− 62	+ 17	24	+ 334	+ 42	+ 188
Neptune	4.1220	+ 180	− 33	+ 74	19	+ 502	+ 95	+ 300

Examining this table, we see that the figures in column 8, headed t_2, are in the most evident accordance with our knowledge of the physical state of the planets, and *their real temperatures in all probability are the means of t_2 and t, θ_2 and θ.* But doubtless these figures cannot be exact, not only in the case of the planets and Sun, but also in the case of the Earth, and they must be regarded only as first approximations. We may suppose, however, that they give a fair idea of the facts. The figures given for the Sun are placed in parentheses, because our theory, assuming the bodies to consist of rigid nuclei surrounded by gaseous atmospheres, cannot be strictly applied to the Sun, which is wholly gaseous.

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[1] In order to calculate the ratio $\frac{U_1}{U}$ the values of a and g are taken from the *Annuaire du Bureau des Longitudes pour l'an* 1898, p. 242. For the Sun, *Mercury*, *Venus*, the Moon, and *Mars*, the equatorial values are taken; for *Jupiter*, *Saturn*, *Uranus*, and *Neptune*, a was calculated from their volumes, and g at the parallel of 30° dividing the surface of the hemisphere into two equal parts (the last on account of collisions of free molecules of gases with the surface of bodies). We assumed the period of rotation of *Uranus* and *Saturn* $= 10^h$, which is the most probable value on account of the oblateness of *Uranus* and the velocities of revolutions of their satellites. For the Earth $a = 6378300\text{m}$, $g = 9.781 \frac{m}{\sec^2}$.

This table shows that the temperature of the atmospheres and surfaces of the smaller bodies, as the Moon, *Mars*, the Earth, *Mercury*, and *Venus*, is low; on the contrary, that of the Sun and great planets, as *Jupiter*, *Saturn*, *Neptune*, is very high. This certainly corresponds with the facts. That the temperature of the Moon is low is the generally accepted opinion, and it has been confirmed by Langley's measurements of its radiant heat.[1] We have found its surface temperature to be between — 36° C. and — 134°, mean about — 85° C.

The same observations apply to *Mars*. Its surface temperature is between — 36° and — 110°, mean about — 73° C., and the great polar snows existing on its surface prove that its temperature is in reality low. According to Schiaparelli snow is observed not only at the poles but sometimes even near the equator.[2]

The surface temperatures of *Mercury* and *Venus* come out higher than for the Earth (about + 40° C. in the case of *Mercury* and +25° C. for the surface of *Venus*) owing to their proximity to the Sun.

The temperature of the Sun is undoubtedly high. We do not know it exactly; our theory, as stated above, cannot be strictly applied to the Sun. I quote below the table of different determinations of the temperatures of the Sun given by Witz:[3]

Newton	1,669,300° C.	Spörer	27,000° C.
Pouillet	1,461	St. Claire Deville	2,500
Zöllner	102,000	Soret	5,801,846
Secchi	5,344,840	Vicaire	1,398
Ericsson	2,726,700	Violle	1,500
Fizeau	7,500	Rosetti	20,000[4]
Waterston	9,000,000		

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[1] S. P. LANGLEY, "The Temperature of the Moon," *National Acad. of Sciences*, 1887. *Fortschritte der Physik*, 43 (3), 71, 1887.

[2] G. V. SCHIAPARELLI, *Himmel und Erde*, 1, 1887; *Fortschritte der Physik*, 44, 3te Abt., 68, 1887.

[3] AIMÉ WITZ, "Sur la température du soleil," *Mondes* (2), 51, 381–385; *Fortschritte der Phys.*, 36, 3te Abt., 78, 1880.

[4] The figures cited by J. SCHEINER (*Strahlung und Temperatur der Sonne*, Leipzig, 1899) differ considerably from those of Witz. Thus, according to Scheiner, Rosetti found the temperature of the Sun to be 9965°, Zöllner 13230° and 61350°, Violle 1550°.

We may add :

Langley - - -	15,000,000° F. = 8,333,000° C.[1]
Abney and Festing - - - -	12,700[2]
Wilson and Gray - - - - -	8,700[3]
Pernter - - - - - - -	30,000[4]
Ebert - - - - - - -	40,000[5]
Guillaume and Christiansen - - -	6,000[6]
Paschen - - - - - - -	5,000[7]

J. Scheiner has shown that this discrepancy is caused by using different laws of radiation, viz., that of Newton, of Dulong and Petit, or of Stefan. Using but one, say Stefan's law, all the determinations based on the magnitude of the solar radiation give nearly the same numerical results, namely about 6000° C.[8] But this is the so-called "effective temperature" of the Sun, *i. e.*, that of a perfectly black body (lampblack) emitting the same quantity of heat as the Sun. But the radiant heat emitted by the photosphere is absorbed by the external atmosphere of the Sun; according to Laplace, only $\frac{1}{12}$ of the Sun's radiation is transmitted by its atmosphere; according to Pickering $\frac{1}{4.64}$, Frost 0.72, and Vogel 0.79 of red and 0.48 of violet.[9] On the other hand, the radiant surface of the Sun is not perfectly black; it is gaseous, and we do not know its emissive power. According to the observations of Rosetti,[10] for instance, the emissive power of the blue flame of a Bunsen's gas burner of infinitely great thickness is a third of that of a perfectly black body. Taking into account all these considerations, we find by means of Stefan's law that the temperature of the radiating strata of the Sun is about 12,000° C. But, doubtless, these strata are superficial, and the interior ones must have a higher temperature. J. Pernter[1] calculated that at the bottom of the chromosphere the temperature must be about 103300° C., if its height is 1500 geographical miles (11,000 km); Zöllner found that the temperature of the surface of the photosphere is 13,230° and at a depth of $\frac{1}{40}$ of the solar radius, 1,112,000° C.[2] Lane computed[3] that the temperature at the center of the Sun is such that the velocity of the molecules of hydrogen is no less than 331 miles a second, which corresponds to a temperature of about 22,000,000° C. According to Ritter[4] it is not less than 31,300,000° C. The great height of some solar protuberances confirms these calculations; they have been observed 560,000 kilometers high; J. Pernter[5] calculated that, in order to glow at that height, the temperature of hydrogen at the solar surface must be 5,868,000° C. The mean height of the protuberances according to Zöllner being 8,000 geographical miles (60,000 km) the temperature at the solar surface must be 1,100,000° C. The interior strata of the Sun must have a very high temperature for hydrogen to remain incandescent at such a distance from the Sun's surface, and it is possible that the mean temperatures of the solar atmosphere and surface which we found above (157,000° C. in the case of the atmosphere and 314,000° C. for the surface) correspond to strata of the Sun's atmosphere deeper than those from which we receive the radiation.

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[1] Langley, *Proc. Amer. Acad.*, 1878, p. 106–113. *Fortschr. d. Phys.*, **36**, 3te Abt., p. 79, 1880.

[2] J. Scheiner, *loc. cit.*, p. 36.

[3] W. E. Wilson and B. L. Gray, *Phil. Trans.*, 185 (A), 1894, 361–369; *Beiblätter*, **19**, 428, 1895.

[4] J. Pernter, "Bemerkungen zur Bestimmung der Sonnen-Temperatur." *Exner's Repertorium der Physik.*, **22**, 1–8, 1886.

[5] J. Scheiner, *loc. cit.*, p. 59.

[6] C. E. Guillaume and Christiansen, see above p. 243.

[7] J. Scheiner; *loc. cit.*, p. 36. [8] J. Scheiner, *loc. cit.*, p. 39. [9] *Ibid.*, p. 48.

[10] F. Rosetti, "Sul potere assorbente, sul potere emissivo termico delle fiamme e sulla temperatura dell' arco voltaico," *Il Nuovo Cimento*, **8**, Series 3, 138–156, 185–203, 1880.

The temperature of *Jupiter* was found to be very high — between 1,320° C. and 4,060° C. All the observations confirm this conclusion. Thus Bond[6] found the emissive power of its surface to be twice that of the best white lead. It is therefore probable that *Jupiter* adds to the reflected sunlight light of its own. Bredikhin, on the basis of his many years' observations of the surface of *Jupiter*,[1] Lohse,[2] J. Scheiner,[3] and others have enunciated the opinion that *Jupiter* is a glowing body.

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[1] J. PERNTER, *loc. cit.* [2] J. SCHEINER, *loc. cit.*, p. 54.

[3] J. H. LANE, "On the Theoretical Temperature of the Sun, etc," *Amer. Jour. of Science*, **50**, 57-74, 1870.

[4] A. RITTER, *loc. cit.*, **6**, 144, 1879. [5] J. PERNTER, *loc. cit.*

[6] BOND, "On the light of the Sun, Moon, *Jupiter* and *Venus*," *Monthly Notices*, **21**, 197-203. *Fortschr. d. Phys.*, **18**, 236, 1862.

Taking the albedo (the fraction of the incident light reflected by the body) of *Mars* as unity, Müller[4] found the albedo of *Jupiter* to be 2.79 (according to Zöllner 2.34), of *Saturn* 3.28 (according to Zöllner 1.87), of *Uranus* 2.73 and of *Neptune* 2.36. Such albedo of *Jupiter*, the appearance of the clear (red) and dark spots on its surface and their continual variation,[5] the different velocity of rotation of the equatorial and other zones of its surface,[6] and particularly its small density (1.33, water as unity) all these facts afford irrefragable proofs of the high temperature of this planet. The dense and opaque atmosphere hides its glowing surface from our view, and we see therefore only the external surface of its clouds.[7] The objective existence of this atmosphere is proved by the bands and lines of absorption in its spectrum.[1] The interesting photograph obtained by Draper, September 27, 1879,[2] in which the blue and green parts are more brilliant for the equatorial zone than for the adjacent parts of the surface, appears to show that *Jupiter* emits its proper light. It is possible that the constant red spot noticed on its surface by several observers, as Gledhill, Lord Rosse and Copeland (1873), Russel and Bredikhin (1876),[3] is the summit of a high glowing mountain. G. W. Hough[4] considers *Jupiter* to be gaseous, and A. Ritter[5] inferred from his formulæ that in this case the temperature at its center would be 600,000° C.

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[1] BREDIKHIN, "Constitution de *Jupiter*," *A. N.*, IC, No. 2354. *Fortschr. d. Phys.*, **36**, 3 Abt., p. 35.

[2] O. LOHSE, "Beobachtungen und Untersuchungen über die physikalische Beschaffenheit des *Jupiters*, etc.," *Publ. d. Astrophys. Obser. zu Potsdam*, **1**, 93–132. *Fortschr. d. Phys.*, **36**, 3 Abt., 35.

[3] J. SCHEINER, "Ueber die physikalische Beschaffenheit der Planeten und Monde," *Naturw. Rundsch.*, **5**, 17–20, 42–44, 69–72. *Beiblätter zu Wied. Ann.*, **14**, 202, 1885.

[4] G. H. MÜLLER, "Helligkeitbestimmungen der grossen Planeten und Asteroiden," *Publ. d. Astrophys. Observ. zu Potsdam*, **8**, 369, 1893.

[5] Numerous observations by Denning, Barnard, Keeler, Holden and others; see *Fortschr. d. Phys.* für 1886, 1889, and other years.

[6] Observations by Denning, A. Bélopolsky, Serafimoff (*Fortschr. d. Phys.* for 1886, 1889, 1890, 1894). According to Bèlopolsky, the period of rotation of the equatorial zones of *Jupiter* is $9^h\ 51^m$, and $9^h\ 55^m$ for latitudes greater than 10°.

[7] The surface temperature of *Jupiter* is very much lower than that of the Sun; consequently the vapor of water may be condensed in opaque clouds at the height where its density is great. On the contrary, upon the Sun the temperature is so high that it can decrease to what is necessary for condensation of vapor only at a height where the density of the solar atmosphere is too inconsiderable to produce dense and opaque clouds.

On account of their great albedo and small density, we may assume that the other great planets, *Saturn*, *Uranus* and *Neptune*, also have high temperatures. These are, however, as I found above, considerably lower than that of *Jupiter*. Broad dark bands and lines are observed in the spectra of all these planets, as in the spectrum of *Jupiter*,[6] which proves that they are surrounded by slightly transparent atmospheres. The great albedo of *Saturn*, found by Müller, may be caused by the reflection from its clouds being more perfect than that of *Jupiter*, which is enveloped probably by the vapors of denser substances. According to Zöllner, the albedo of *Saturn* is, however, less than that of *Jupiter*.

Respecting the composition of the atmospheres of the planets, we can deduce some conclusions in the manner adopted by the present author in 1884 (*Journal of the Russian Physical and Chemical Society*, **16**, 524–538). The following is an extract:

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[1] H. C. VOGEL, *Untersuchungen über die Spectra der Planeten*, Leipzig, 1874, and "Neue Untersuch ü. d. Spectra d. Planeten." *Sitzungsber. d. Akad. d. Wissensch. zu Berlin*, pp. 1–25, 1895. Also J. SCHEINER, *Die Spectralanalyse der Gestirne*, pp. 215–219, 1890.

[2] J. SCHEINER, *Spectralanalyse der Gestirne*, p. 219.

[3] W. F. DENNING, *Nature*, 58, 331–332, 1898; *Beiblätter zu d. Annal. d. Phys. und Chem.*, 23, 421, 1899.

[4] G. W. HOUGH, *Fortschr. d. Phys.*, 50 (3), 77, 1894.

[5] A. RITTER, *loc. cit.*, *Wied. Ann.*, 20, 921, 1883.

[6] J. SCHEINER, *Spectralanalyse*, pp. 215–224.

According to Maxwell's kinetic theory of gases their molecules are constantly flying with all possible velocities and in all conceivable directions, but there is in every gas a certain most probable velocity (*i. e.*, a velocity that differs but little from the velocities of the greater part of the molecules, depending only on the temperature and the nature of the gas.[1] Thus, the most probable velocity of the molecules of hydrogen at 0° C. is 1500 meters per second, vapor of water 502, nitrogen 401, air 395, oxygen 376. For carbon dioxide it is 320 and for the recently discovered helium, 1064 meters per second.

On the other hand it is shown in mechanics that, if the velocity of a material point subjected to the attraction of a body is greater than $\sqrt{2ag_0}$, where a is the radius of this body, and g_0 the acceleration of gravity at its surface, then this point travels in a parabola or hyperbola, and having once attained the surface of the body, streams away from it into infinity and never returns to it. Hence, if the most probable velocity of the molecules of any gas upon a certain celestial body have a value of about $\sqrt{2ag_0}$, this gas cannot be retained at the surface of the body.[2]

The following table gives an idea of this subject.

TABLE II.

(See the footnote on p. 244)

Name of body.	Mean distance from the Sun.	Mass m compared to that of the Earth.	DENSITY.		Radius a referred to that of the Earth as unity.	Acceleration g referred to that of the Earth as unity.	$\sqrt{2ag}$ meters per second.
			Compared to that of the Earth.	Compared to that of water.			
Sun......	.....	324439.	0.253	1.39	108.56	27.625	611700
Mercury..	0.387	0.061	1.173	6.45	0.373	0.439	4520
Venus....	0.723	0.787	0.807	4.44	0.999	0.802	9998
Earth....	1.	1.	1.	5.50	1.	1.	11170
Moon....	1.	0.013	0.615	3.38	0.273	0.174	2434
Mars.....	1.524	0.105	0.711	3.91	0.528	0.376	4997
Jupiter...	5.203	309.816	0.242	1.33	10.856	2.462	57751
Saturn ...	9.539	91.919	0.128	0.70	8.058	1.014	33662
Uranus...	19.183	13.518	0.195	1.07	4.106	0.739	19456
Neptune..	30.055	16.469	0.300	1.65	3.798	1.0853	22679

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[1] This velocity $= \sqrt{\frac{2}{3}}\, V$, where $V = \sqrt{\frac{3p}{\rho}}$ is the velocity of mean square, *i. e.*, the velocity the square of which is the mean of the squares of the velocities of all the individual molecules of a gas; p is the pressure and ρ the density of a gas. (See the footnote 1 on page 235.)

[2] The idea of the dependence of the presence of any gas in the atmosphere on

By comparison of the magnitudes of $\sqrt{2ag_0}$ with the most probable velocities of the molecules of several gases given above, we may conclude that the existence of vapor of water and, still more, of oxygen and nitrogen on the great planets is quite probable; on the contrary, their existence to any sensible extent upon the Moon and the small planets, for instance the asteroids, is hardly probable. Upon the Sun and great planets, for which $\sqrt{2ag}$ has a considerable magnitude, gases may exist of such small atomic weight that they cannot be present upon the Earth. It is possible that they are the elements giving certain lines in the Sun's spectrum, which cannot be identified with those of any terrestrial elements.

Knowing the temperatures of the atmospheres and surfaces of the planets, we may now deduce more precise conclusions on the composition of their atmospheres by proceeding as Dr. G. J. Stoney[1] has done.

As is known, the new element helium (atomic weight 2), was discovered by Ramsay in the gases imprisoned in the pores of the rare uranite minerals, such as clèveite, bröggerite, and others.[2] It is constantly supplied to the Earth's atmosphere by certain hot springs and volcanoes, and consequently if it could be retained by the Earth to any sensible extent, it would certainly accumulate in our atmosphere in the lapse of geological ages; but only a trace of helium is found in the atmosphere by H. Kayser,[3] Friedländer,[4] and Crookes.[5] Hence helium marks the

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the ratio of the velocity of its molecules to the value of $\sqrt{2ag_0}$ has been treated by G. J. Stoney (ASTROPHYSICAL JOURNAL, **7**, 25–55, 1898), and the author, and has also been enunciated by G. HANSEMANN (*Die Atome und ihre Bewegungen*, Cöln, 1871, p. 97), TOLVER PRESTON (*Nature*, **19**, 3, 1878), H. BALL (*Science*, **21**, 99, 1893), C. H. BRYAN (*Science*, **22**, 311–313, 1893), and C. E. GUILLAUME (*Séances de la Société française de Phys.*, 1894, p. 258); but J. J. Waterston, in 1845, was the first to communicate this view to the Royal Society of London. His remarkable memoir, however, in which he deduced all the most important principles of the kinetic theory of gases, and gave a strict proof of its principal formula, was first printed by Lord Rayleigh in 1893 (J. J. WATERSTON, "On the Physics of Media that are Composed of Free and Perfectly Elastic Molecules in a State of Motion," *Phil. Trans.*, **183** A, 1893), and hence it remained unknown till then.

[1] G. JOHNSTONE STONEY, "Of Atmospheres upon Planets and Satellites," ASTROPHYSICAL JOURNAL, **7**, 25–55, 1898.

[2] RAMSAY, *Journ. Chem. Soc.*, **67**, 684–701, 1895; *Beiblätter*, **19**, 673, 1895.

[3] H. KAYSER, *Chem. News*, **72**, 89, 1895, and BOUCHARD, *Compt. Rend.*, **121**, 392–394, 1895; *Beiblätter*, **19**, 827, 1895.

[4] FRIEDLÄNDER, *Zeitschr. f. Physik. Chemie*, **19**, 657–667, 1896; *Beiblätter*, **20**, 775, 1896.

[5] CROOKES, *Chem. News*, **78**, 197–198, 1898; *Beiblätter*, **23**, 357, 1899.

boundary between the gases which can escape from the Earth and those which can not: all gases lighter than helium escape from the Earth, and all heavier are retained by it. Gases and vapors with atomic weights between 2 (helium) and 7 (lithium) are not found on the Earth, either because they do not exist, or because they were dissipated from the Earth when it was warmer than now. Helium and even hydrogen were retained in our atmosphere, mainly in its upper layers,[1] as being the constituents of the interplanetary medium, which may be considered as a continuation of the atmosphere of the Sun.

The most probable velocity of the molecules of helium is 1093 meters per second at 15°C., *i. e.*, at the mean temperature of the Earth's surface. $\sqrt{2ag}$ for the Earth is $11170\frac{\text{km}}{\text{sec}}$.[2] Consequently, if the most probable velocity of the molecules of a gas or a vapor is $\sqrt{2ag}$ divided by 10.22 $\left(i.\ e.,\ \frac{11170}{1093}\right)$, corrected for centrifugal force, the gas or the vapor is not retained at the surface of the given celestial body. Thus the equation

$$W=\frac{\sqrt{2ag}}{10.22},$$

where W is the most probable velocity of the molecules of a gas, gives the minimum most probable velocity in a gas which escapes from the surface of the given celestial body. But we have

$$W=\sqrt{\frac{2p}{\rho}\cdot\frac{T}{273}}\ ^{3}$$

or

$$W=\sqrt{\frac{2p}{\rho_1\delta}\cdot\frac{T}{273}}$$

where ρ_1 is the density of hydrogen and δ, the density of the given gas referred to hydrogen as unity; $\sqrt{\frac{2p}{\rho_1}}$ is the most probable velocity at 0°C., in hydrogen, $1505\frac{m}{\text{sec.}}$. Hence we have the equation

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[1] See p. 255 below.

[2] See Table II, p. 250. [3] See footnote 1 on p. 250.

$$1505\sqrt{\frac{1}{\delta}\cdot\frac{T}{273}}=\frac{\sqrt{2ag}}{10.22}\,.$$

Substituting for $\sqrt{2ag}$ the values taken from Table II, and for T the absolute temperature at the surface of the planets, taken from Table I, we can determine the density δ (hydrogen = 1) of gases which escape from the given celestial body as freely as helium does from the Earth.

If for T we put in the above equation 131°, assumed as the absolute temperature of celestial space and, at the same time, as the temperature of the upper strata of the atmospheres of the planets and the Sun, we obtain the maximum density of gases which escape from the atmospheres of the celestial bodies.

The first column of Table III contains the names of the celestial bodies; the second, $\frac{U_1}{U}$, the ratio of the potential functions of gravitation, corrected for rotation at the surface of the body to that at the surface of the Earth; the third, the mean temperatures of the surfaces of the bodies taken from Table I; the fourth, the densities of gases referred to that of hydrogen as unity, which escape from the surface of the bodies as freely as helium does from the Earth's surface; the fifth column, the density of gases not retained in the upper strata of the atmospheres; the sixth column gives Dr. Stoney's numbers for the densities of gases escaping from the upper strata of the atmospheres of the bodies as freely as helium escapes from the Earth's atmosphere. We see that they have greater values than the figures in the sixth column, for Dr. Stoney[1] has taken for the temperature of the upper limits of the atmospheres of the planets and the Earth −66°C. The last assumption cannot be admitted on account of the temperature −69.8°C. being observed at the surface of the Earth, and −75°C. at 11,000 meters.[2]

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[1] *Loc. cit.*, p. 34 and following.

[2] See p. 241 and footnote 3 on p. 239.

TABLE III.

Name of Body.	$\frac{U_1}{U}$	Temperature at the Surface.	MAXIMUM DENSITY OF THE GAS[1] (H=1).		G. J. Stoney's Results.
			Not Retained at the Surface.	Not Retained at the Upper Strata of the Atmosphere.	
Sun............	2998.4	+314000° C.	0.721	0.000304	.....
Mercury........	0.16375	+40	13.0	5.6	10–11
Venus..........	0.8012	+25	2.6	1.25	.....
Earth..........	1	+15	2	0.9	2
Moon..........	0.04750	−85	28	19	39
Mars............	0.19855	−73	6.9	4.6	9.57
Jupiter.........	26.738	+2690	0.76	0.05	0.099
Saturn.........	9.0814	+827	0.82	0.17	0.37
Uranus.........	3.0337	+188	1.0	0.44	0.74
Neptune........	4.1220	+300	0.94	0.30	0.68

Multiplying the numbers of the fourth and fifth columns by $\sqrt{\frac{9}{2}}$, we shall get the densities of gases which are retained at the surface and in the upper strata of the atmospheres as firmly as is water vapor in the Earth's atmosphere.

From the above table we see that the atmosphere of the Sun may contain not only hydrogen, but also gases many times lighter than hydrogen, if any such exist.

Owing to the lower temperature of the upper strata of the atmospheres, they can contain gases and vapors which cannot exist in the lower layers. Thus, in the higher strata of the Earth's atmosphere, helium and, perhaps, even hydrogen may be retained. In fact, the helium line λ 5015.9[2] may perhaps correspond with the line λ 5000.5, observed by Vogel, Capron,[3] and others in the spectrum of the aurora borealis, and by Vogel and Schuster[4] in the spectrum of lightning ($\lambda = 5002\,\mu\mu$). It is not possible to determine what element produces these lines of the aurora borealis and lightning. Exact measurement under the given conditions is attended with great difficulty, as appears from the fact that the differences in the wave-length of the characteristic yellow-green line of the aurora borealis (λ 5570.9)[1] measured by various observers reaches about 1.6 meters.[2] In like manner, many lines of the aurora borealis given by Professor Vogel[3] are near the lines of rarefied hydrogen as given by Hasselberg.[4] On June 18, 1897, at the Arequipa Observatory, the spectrum of a meteor was photographed, containing six lines at wave-lengths 3954, 4121, 4195, 4344, 4636, 4857, and the corresponding intensities of about 40, 100.2, 13, 10, 10. Four of these lines, viz., the first, the second, the fourth, and the sixth are not far from the hydrogen lines $H\epsilon$ (λ 3970.), $H\delta$ (λ 4101), $H\gamma$ (λ 4341), and $H\beta$ (λ 4862).[5] In fact, helium is present even at the surface of the Earth, as is shown by the experiments of Kayser, Friedländer and Crookes,[6] and a trace (0.02 per cent.) of free hydrogen has now been discovered by A. Gautier.[7] These gases are carried from the upper to the lower strata of our atmosphere by currents of air. It is possible, also, that the green line of the spectrum of the aurora borealis is due to coronium, which is, probably, an element lighter than hydrogen, being observed only in the upper regions of the Sun's atmosphere, or to other unknown elements lighter than hydrogen.

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[1] Referred to hydrogen as unity; it is equal to atomic weight for elementary gases.

[2] W. CROOKES, *Zeitschr. anorg. Chem.*, **11**, 6–13, 1896; *Beiblätter*, **20**, 275, 1896.

[3] J. SCHEINER, *Die Spectralanalyse der Gestirne*, p. 335, Leipzig, 1890.

[4] H. KAYSER, *Lehrbuch der Spectralanalyse*, p. 115.

In the atmosphere of the Moon, not only such gases as oxygen, nitrogen, and vapor of water cannot be retained, but even carbon dioxide ; the denser gases, owing to the low temperature prevailing on the Moon (−85° C.), can be only in the fluid or solid state, and therefore, if the Moon has an atmosphere, it must be of insensible density. This opinion has been confirmed by the most careful observations of the occultations of stars by the Moon. According to Pickering,[1] the density of the Moon's atmosphere is not greater than $\frac{1}{4000}$ of that of the Earth's atmosphere. Spectroscopic observations lead to the same conclusion: by reflection of the sunlight from the surface of the Moon the Fraunhofer lines are not strengthened and no new lines or bands appear in the spectrum.[2]

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[1] Perhaps this line belongs to some unknown element lighter than helium.

[2] J. Scheiner, *loc. cit.*, p. 336.

[3] *Id.*, p. 325.

[4] H. Kayser, *Lehrbuch der Spectralanalyse*, p. 279.

[5] E. C. Pickering, "Spectrum of a Meteor," *A. N.*, **145**, 3461, 1898.

[6] See p. 251.

[7] A. Gautier, *Bulletin de la Société chimique de Paris*, Dec. 5, 1900, p. 884; *Beiblätter*, **25**, 2, 1901.

Upon *Mercury*, at least on the side exposed to the sunlight, not only vapor of water but even oxygen and nitrogen cannot, probably, remain in the inferior strata of its atmosphere; these gases can accumulate only on the dark side and in the upper strata. Spectroscopic observations yield contradictory results, being very difficult owing to the small distance of the planet from the Sun. While some observers found the telluric lines in the spectrum of *Mercury* to be stronger, indicating the presence of an atmosphere like that of the Earth,[3] Professor Vogel did not observe this.[4]

The composition of the atmospheres of *Venus* and *Mars* may be the same as that of the Earth; but the force of gravity on these planets being less, their atmospheres must be less dense than that of the Earth, particularly on *Mars*. It is probable that water vapor exists even in the atmosphere of Mars, but in consequence of its low temperature in less quantity than in our atmosphere. This is confirmed by the spectroscopic observations of Huggins and Maunder, and particularly by the careful observations made during many years by Professor Vogel,[5] which show that in the spectra of these planets some of the telluric lines are stronger. W. W. Campbell[1] did not observe such a selective absorption in the case of *Mars*, and this shows that the density of its atmosphere and especially of the vapor of water cannot be great. In consequence of the low temperature on *Mars* (between −110° and −36°, mean −73° C.) the water upon its surface must be mainly in the solid state, carbon dioxide in the gaseous and solid state[2] and only oxygen and nitrogen as gases. Its distance from the Sun being 1.5 that of the Earth, the heat received by *Mars* from the Sun's radiation is only half of that received by the Earth, and the polar ice and snows which we see melting upon its surface when exposed to solar radiation are probably composed of carbon dioxide or some other body freezing at a temperature near −73° C., for otherwise this ice could not melt so quickly as it is observed to do.[3] Being a denser constituent of the atmosphere, vaporized carbon dioxide cannot rise or form clouds like aqueous vapor on the Earth. It passes along the surface of *Mars* to its equator at the bottom of the atmosphere by canals and valleys, raising the lighter constituents. Water vapor may then form clouds, but composed of spicules of ice like our cirrus, which probably cause the gemmination of the canals, like the muslin in the experiments of H. Meunier.[4] Reflecting the Sun's rays, these clouds possibly produce the projections observed by Douglass in 1900 and Gledhill in 1899. Ordinary clouds and rain cannot exist on *Mars*; its polar white spots are perhaps hoar frost, like that which settles on our trees and earth, directly condensed from the atmosphere.

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[1] W. H. PICKERING, *Astronomy and Astro-Physics*, **11**, 778–781, 1892; *Fortschr. d. Phys.* **48** (3), 60, 1893.

[2] J. SCHEINER, "Ueber die physikalische Beschaffenheit der Planeten und Monde," *Naturw. Rundschau.*, **5**, 17–20, 41–44, 69–72, 1883. *Fortschr. d. Phys.*, **42**, (3), 100–106, 1886.

[3] *Ibid.*

[4] H. C. VOGEL, *Neue Untersuchungen über die Spectra der Planeten.* Leipzig, 1874.

[5] *Ibid.*, and J. SCHEINER, the above footnote. According to Stoney there is no water.

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[1] W. W. CAMPBELL, "The Spectrum of the Planet Mars," *Astronomy and Astro-Physics*, **13**, 752–760, 1894; *Fortschr. d. Phys.*, **50**, 58, 1894; **51** (3), 60, 1895.

[2] Carbon dioxide at the ordinary atmospheric pressure boils at −79° C.; at 5 mm pressure it boils at −125° C., and freezes at the same time; when the pressure is lower than 760 mm (and even 5 atmospheres) as upon *Mars*, carbon dioxide passes directly from the solid to the gaseous state. (*P. Villard* et *Jarry*. "Neige carbonique." *Comptes Rendus*, **120**, 1413–1416, 1895; *Séances de la Société française de physique*, 1895, 177–185).

[3] S. MEUNIER, "Cause possible de la gemmination des canaux de *Mars*." *Comptes Rendus*, **115**, 678–680, 901–902, 1892; *Géologie comparée*. Paris, 1896. Meunier took a polished metal ball on which black stripes were traced, representing the canals of *Mars*, and enveloped it in muslin; when a beam of light was incident on it, these black stripes were seen accompanied by others, parallel to them, which were produced by their shadows cast on the muslin envelope.

[4] *Ibid.*

As free oxygen and carbon dioxide may exist in the atmosphere of *Mars*, vegetable and animal life is quite possible. If the temperature which prevails upon *Mars* is nearer to —36° C. than to —73° C., the existence of living beings like ourselves is possible. In fact, the ice of some Greenland and Alpine glaciers is covered by red algae (*Sphaerella nivalis*); we find there, also, different species of rotatoria, variegated spiders, and other animals on the snow fields illuminated by the Sun; at the edge of glacier-snows in the Tyrol we see violet bells of *Soldanella pusilla*, the stalks of which make their way through the snow by producing heat which melts it round about them[1]. Finally, the Siberian town of Verkhoiansk, near Yakutsk, exists though the temperature there falls to —69°.8 C., and the mean temperature of January to —51°.2, and the mean pressure of the vapor of water is less than 0.05 mm.[2] It is possible, therefore, that living beings have become adapted to the conditions now prevailing upon *Mars* after a lapse of many ages, and live at an even lower temperature than upon the Earth, developing the necessary heat themselves.

If the temperature on *Mars* is near to —73° C., or lower, the part played by water may there be played by another substance remaining liquid at —73° C. Water in organisms is mainly a liquid medium or solvent, and many other liquids may be the same. We have no reason to believe that life is possible only under the same conditions and with the same chemical composition of organisms as upon the Earth, although, indeed, we cannot affirm that they actually exist on *Mars*.

The atmospheres of the planets *Jupiter*, *Saturn*, *Uranus*, and *Neptune* may contain gases lighter than the Earth can retain, and even lighter than hydrogen, if any such exist. In consequence of more intense gravitation, the density and the height of their atmospheres must be greater than on the Earth. The spectroscopic observations of Secchi, Vogel, Huggins, Janssen, Keeler, and Lockyer confirm these deductions, because the spectra of these planets, besides the ordinary solar and telluric lines, contain some other dark lines and bands, so that the composition of their atmospheres undoubtedly differs from that of the Earth.[1]

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[1] A. KERNER V. MARILAUN, *Pflanzenleben*.

[2] W. OVERMANN'S *Jahrb. d. Naturwissenschaften*, 13, 278, 1897–8.

Table I may give us a complete idea of the climatic conditions upon the planets. So we see, for instance, that the temperature at the surface of *Mercury* is high owing to strong heating by the Sun, although its own heat is small. Owing to this heating, the difference between the temperatures of the illuminated and dark sides must be very great, particularly since the same side of this planet is always turned to the Sun. The same is true for *Venus*, though in less degree; as its temperature is almost like that of the Earth (+ 25° C.) it is possible that life may exist on its surface. On the contrary, for the great planets *Jupiter* and, in particular, *Saturn*, *Uranus* and *Neptune*, owing to the small heating by the Sun, the temperature is almost uniform over the whole surface and without sensible diurnal and annual variations.

In conclusion, I wish to call attention to a single circumstance. If in formula (7) ρ, the density of a gas at the Earth's surface, is made equal to unity, we obtain

$$ak_0 \log. \rho_1 = \frac{a_1 g_1}{T_1} - \frac{ag}{T} \ ;$$

differentiating with respect to ρ and T, we have

$$\frac{d\rho_1}{\rho_1} = \frac{1}{ak_0} \cdot \frac{a_1 g_1}{T_1} \cdot \frac{dT_1}{T_1} \ .$$

Since $\frac{a_1 g_1}{ak_0 T_1} = \frac{ag}{ak_0 T}$ is about 3000,[2] we see that a small variation of the temperature of a celestial body produces a large variation in the density of its atmosphere, owing to the passage of gases from the interplanetary medium into the atmosphere, or conversely. This alters the mass of the heavenly body, which may have some influence on its motion. Likewise, the asymmetrical heating, produced by the Sun's radiation, of the surface of such planets as *Mercury* and *Venus*, which always turn the same face to the Sun, must increase the asymmetry of the body by the condensation of matter on the side turned away from the Sun.

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[1] J. SCHEINER, *Die Spectralanalyse der Gestirne*, p. 210.

[2] See p. 236.

The above results certainly cannot pretend to be exact, the distribution of temperature through interplanetary space being completely unknown; but they show that even such apparently accidental circumstances as the temperature and composition of the atmospheres of celestial bodies, are in fact not accidental, but necessary consequences of the general laws of universal gravitation, radiant heat, and the nature of gases. In reality, the atmospheres of all the planets and of the Sun are in material connection, and phenomena occurring upon one of them, at least on the Sun, affect the rest, although after a considerable time. As science advances we may expect more precise knowledge regarding the atmospheres of celestial objects. It is perhaps not too much to hope that observational means of verifying the results derived from theory may ultimately be available. In any event, there is every season to anticipate that many questions of astrophysics will be cleared up through advances in the spectroscopic and photometric study of radiation.

ST. PETERSBURG,
September, 1901.

MINOR CONTRIBUTIONS AND NOTES

OBSERVATIONS OF THE SPECTROSCOPIC BINARY *CAPELLA.*[1]

THE first magnitude star *Capella* was discovered to be a spectroscopic double star early in August, 1899, from an examination of the plates of its spectrum secured with the Mills spectrograph in 1896. Announcement of the fact was made to the Astronomical and Astrophysical Society of America at the meeting of September 7, 1899, and in the ASTROPHYSICAL JOURNAL for October, 1899.

Independent discovery of its binary character was made by Mr. H. F. Newall, of Cambridge, England, in November, 1899, and announced in the *Monthly Notices of the Royal Astronomical Society* for November.

The spectra of the two components are distinguishable on most of the plates — the exceptions being those taken when the radial velocities of the two were nearly equal, producing a superposition of the two sets of lines. The spectrum of the principal star is of the solar type, whereas that of the secondary is intermediate between the solar and Sirian types.

The velocities of the principal component, as observed with the Mills spectrograph, are given in the following table:

No.	Date. Greenwich M. T.			Velocity. Kilometers.	No.	Date. Greenwich M. T.			Velocity. Kilometers.
1	1896	Sept.	1.036	+36.4 C	17	1899	Nov.	6.026	+54.8 C
2			17.005	53.8 C	18			27.952	43.2 W
3		Oct.	4.003	50.3 C	19			27.966	44.0 W
4			6.029	46.9 C	20		Dec.	3.730	35.2 C
5		Nov.	12.865	4.2 C	21			18.648	12.6 W
6	1899	Aug.	12.999	48.3 C	22			24.882	7.7 W
7			27.052	26.1 C	23	1900	Jan.	10.649	7.7 C
8		Sept.	12.950	5.7 W	24			21.740	21.7 W
9			20.006	5.1 W	25		Feb.	11.724	50.0 W
10			20.919	3.5 W	26			26.726	55.2 W
11			20.933	5.4 W	27			26.740	54.8 C
12			25.909	6.6 C	28		Aug.	2.012	3.6 C
13		Oct.	3.988	14.8 C	29		Sept.	19.944	55.5 C
14			16.012	32.9 C	30			24.950	53.9 C
15			16.929	32.0 C	31			27.005	53.7 C
16			31.892	52.0 C					

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[1] *Lick Observatory, University of California, Bulletin* No. 6.

[Measures of the plates by Campbell and Wright are indicated by C and W respectively.]

The presence of the second component's spectrum interferes considerably with the measures of that of the first component, and the probable error of a single observation, ± 0.50 kilometer, deduced by Dr. Reese, is as small as could be expected. Measures of the speed of the second component are somewhat uncertain, but an estimated range of from − 3 to + 63 kilometers will not be far from the truth. The velocity of the principal component in the line of sight ranges from + 4.2 to + 55.7 kilometers. The masses of the two components are therefore as 1.26 to 1.

The solar-type component is estimated to be half a magnitude brighter, photographically, than the bluer component. In the visual portion of the spectrum the solar component is probably at least a whole magnitude the brighter of the two.

Inasmuch as the spectroscope takes account of the component of speed in the line of sight, and is powerless to measure the component at right angles to the line of sight, the spectroscopic orbit is determinate in form but indeterminate in size. The inclination of the orbit-plane remains unknown. The minimum orbit capable of satisfying the observed velocities corresponds to the case of the orbit-plane passing through the observer. In this case the maximum distance between the two components would be about 85,000,000 kilometers; and, if Elkin's value of the parallax of *Capella*, 0″.08, is correct, the angular separation of the components, as viewed from the solar system, would approximate 0″.045 when passing through the nodes. Such an orbit would give rise to eclipses every fifty-two days. No variations in the brightness of *Capella* having been observed, it is safe to assume that the orbit-plane makes an appreciable angle with the line of sight.

In the case of a great number of orbit-planes distributed fortuitously, the most probable value of the angle between the normal to the orbit-plane and the line of sight would be 60°. The corresponding angular separation of the components at the nodal points would be about 0″.052. In case this angle should be 30°, the corresponding separation would be 0″.09.

The question as to whether *Capella* could be observed as an ordinary double star early arose. It was most carefully examined with the 36-inch refractor on several occasions in 1900 and 1901 by Messrs. Hussey and Aitken, and on one occasion by Mr. Perrine; but neither duplicity nor elongation could be detected. Their observations were made under the most favorable conditions, and we may conclude that the angular separation of the components is less than 0″.06.

A discussion of the probable masses of the components with reference to the mass of our Sun seems to be futile, on account of the impossibility of harmonizing the best available data for the parallax and brightness of *Capella*, the brightness of our Sun, and the angular separation of the components. W. W. CAMPBELL.

JULY 25, 1901.

A DETERMINATION OF THE ORBIT OF *CAPELLA*.

The announcement that *Capella* is a spectroscopic binary was made by Professor Campbell in the ASTROPHYSICAL JOURNAL for October, 1899, and afterwards by Mr. H. F. Newall in the *Monthly Notices of the Royal Astronomical Society* for November, 1899. It will be recalled that Vogel and Scheiner had photographed the spectrum from October 6, 1888, to September 15, 1889; but failed to detect its binary character, their spectroscope being apparently incapable of resolving the composite spectrum. Consequently their measurements give the mean displacements of two sets of lines, and their reductions an approximation to the velocity of the center of mass of the system.

The following computation is based on thirty-one observations of the velocity in the line of sight of the solar-type component, made with the Mills spectrograph at intervals between September 1, 1896, and September 27, 1900. The plates were exposed and the measurements and reductions carried out by Director Campbell and Mr. W. H. Wright. The method of computing the orbit is exactly that given by Lehmann-Filhés (*Astronomische Nachrichten*, No. 3242), except that in the equations of condition the correction to the velocity of the center of mass of the system is introduced as a sixth unknown, with coefficient unity. The period 104.1 days was assumed as best agreeing with the observations, and the observed velocities were plotted as functions of the time-interval after the next preceding minimum, assuming September 18.9, 1899, as a time of minimum. A smooth curve was drawn through the points so obtained, and by means of a planimeter the line representing the velocity of the center of mass of the system was drawn so as to enclose equal areas with the portions of the curve above it and below it. The other requisite quantities were then obtained in the way shown in the article already cited. The following is the list of provisional elements thus found:

$U = 104.1$ days, period.

$\left.\begin{array}{l}\mu = 3^\circ\!.4582 \\ \quad = 0.060357 \text{ radians}\end{array}\right\}$ average daily motion.

$\omega = 123^\circ\!.041$, position of periastron.

$T = -15.8$ days, time of periastron passage from September 18.9, 1899.

$e = 0.02$, eccentricity of orbit.

$a \sin i = 36{,}997{,}900$ kilometers.

$$K = 25.85 = \frac{\mu}{\sqrt{1-e^2}} \cdot \frac{a \sin i}{86400} \, .$$

$V = +30.0$ kilometers per second, velocity of center of mass of system.

Before computing an ephemeris with these elements, certain of the observations were combined in pairs so as to form in all twenty-seven normal places. These were weighted on the assumption that all the thirty-one original observations were equally reliable; that is, a normal place formed by combining two observations was given weight 2, and all uncombined observations weight 1.

No.	Date. Gr. M. T.			Observed Velocity.	O—C Prelim. Orbit.	O—C Final Orbit.	Comparison of Residuals.
				Kilometers.	Kilometers.	Kilometers.	Kilometers.
1....	1896	September	1.036	+36.4	−2.13	−0.83	+0.11
2....			17.005	53.8	−0.63	−0.38	+0.04
3....		October.... ...	4.003	50.3	+1.11	+0.08	−0.03
4....			6.029	46.9	−0.05	−1.20	−0.05
5....		November......	12.865	4.2	+0.30	−0.02	−0.04
6....	1899	August	1[illegible].999	48.3	+1.24	+1.09	+0.01
7....			27.052	26.1	−0.16	−0.43	0.00
8....		September	12.950	5.7	+0.02	−0.39	0.00
9....			20.006	5.1	+1.18	+0.84	0.00
10....			20.919	3.5	+0.43	−0.86	+0.01
11....			20.933	5.45		+1.08	
12....			25.909	6.6	+0.47	+0.24	−0.02
13....		October........	3.988	14.8	+0.98	+0.92	+0.01
14....			16.912	32.9	+0.19	+0.65	+0.01
15....			16.929	32.0		−0.28	
16....			31.892	52.0	+0.99	+0.84	−0.01
17....		November......	6.026	54.8	+0.41	+0.24	0.00
18....			27.952	43.2	+0.14	−0.34	+0.01
19....			27.966	44.0		+0.48	
20....		December......	3.720	35.2	+0.22	+0.14	+0.01
21....			18.646	12.6	+0.13	−0.17	−0.02
22....			24.882	7.7	+1.26	+0.91	0.00
23....	1900	January........	10.649	7.7	−0.42	−0.66	0.00
24....			21.740	21.7	+0.30	+0.18	0.00
25....		February.......	11.724	50.0	+0.12	−0.08	0.00
26....			26.726	55.2	−0.03	+0.04	+0.04
27....			26.740	54.8		−0.36	
28....		August....... .	2.012	3.6	−1.34	−1.70	−0.02
29....		September	19.944	55.5	−0.06	−0.24	−0.01
30....			24.950	53.9	−0.32	−0.34	+0.02
31....			27.005	53.7	+0.69	+0.72	−0.03
				[*pvv*]	16.820	13.988	

The accompanying table gives the data of the observations. The date is given in the second column and the observed radial velocity relative to the Sun in the third. The observations combined to form normal places are the tenth and eleventh, the fourteenth and fifteenth, the eighteenth and nineteenth, and the twenty-sixth and twenty-seventh. Column 4 gives the residuals from the velocities computed with the above provisional elements. It will be seen that the greatest residual in absolute amount is 2.13 kilometers, and the sum $[pvv]$, 16.820.

The equations of condition formed according to the method of Lehmann-Filhés are given below, each equation being followed by its weight:

$+0.330\,\delta K$	$-3.16\,\delta e$	$+23.87\,\delta\omega$	$-25642\,\delta\mu$	$-1.412\,\delta T$	$+\delta V+2.13=0$	1
$+0.945$	-23.76	$+7.17$	-7969	-0.445	$+0.63=0$	1
$+0.742$	$+19.64$	-17.44	$+18207$	$+1.033$	$-1.11=0$	1
$+0.656$	$+23.22$	-19.71	$+20692$	$+1.176$	$+0.05=0$	1
-1.010	-11.75	$+0.91$	-1410	-0.083	$-0.30=0$	1
$+0.660$	$+23.09$	-19.60	$+409$	$+1.170$	$-1.24=0$	1
-0.145	$+8.06$	-26.05	$+187$	$+1.603$	$+1.16=0$	1
-0.941	-25.20	-9.94	-98	$+0.594$	$-0.02=0$	1
-1.009	-11.37	$+1.12$	$+27$	-0.096	$-1.18=0$	1
-1.004	-8.64	$+2.60$	$+55$	-1.186	$-0.43=0$	2
-0.923	$+6.86$	$+10.15$	$+243$	-0.643	$-0.47=0$	1
-0.626	$+24.34$	$+19.95$	$+622$	-1.215	$-0.98=0$	1
$+0.088$	$+9.37$	$+25.29$	$+1098$	-1.512	$-0.19=0$	2
$+0.813$	-25.17	$+14.22$	$+831$	-0.853	$-0.99=0$	1
$+0.944$	-23.86	$+7.29$	$+479$	-0.452	$-0.41=0$	1
$+0.521$	$+25.83$	-22.33	-1913	$+1.345$	$-0.14=0$	2
$+0.192$	$+21.84$	-25.75	-2387	$+1.572$	$-0.22=0$	1
-0.678	-20.02	-19.70	-2136	$+1.210$	$-0.13=0$	1
-0.912	-25.84	-11.67	-1342	$+0.702$	$-1.26=0$	1
-0.847	$+14.31$	$+13.76$	$+1840$	-0.857	$+0.42=0$	1
-0.333	$+24.18$	$+24.04$	$+3360$	-1.442	$-0.30=0$	1
$+0.769$	-24.12	$+15.75$	$+2520$	-0.941	$-0.12=0$	1
$+0.968$	-4.33	-5.69	-916	$+0.313$	$+0.03=0$	2
-0.970	$+0.04$	$+6.92$	$+2476$	-0.449	$+1.34=0$	1
$+0.989$	-12.89	-1.14	-265	$+0.042$	$+0.06=0$	1
$+0.937$	$+1.86$	-8.69	-3162	$+0.493$	$+0.32=0$	1
$+0.890$	$+8.11$	-11.64	-4337	$+0.673$	$-0.69=0$	1

These equations were rendered more nearly homogeneous by dividing the coefficients of δe by 10, those of $\delta\omega$ by 10, and those of $\delta\mu$ by 1,000. The normal equations were then found to be as follows:

$+18.944\,\delta K$	$+3.918\,\delta e'$	$-6.638\,\delta\omega'$	$+1.642\,\delta\mu'$	$+4.024\,\delta T$	$+1.619\,\delta V$	$+1.068=0$
	$+96.913$	-16.972	$+108.588$	$+10.295$	$+1.287$	$-2.194=0$
		$+80.515$	-86.551	-48.520	-2.644	$+7.921=0$
			$+1563.748$	$+51.160$	-0.207	$-73.384=0$
				$+29.252$	$+1.300$	$-4.653=0$
					$+31.000$	$-5.77=0$

The solution gave the following corrections to the provisional elements:

$\delta\mu = +\ 0.0000453$ radians.
$\delta\omega = -\ 0.0995$ radians $= -\ 5^{\circ}.6990$
$\delta T = -\ 1.553$ days.
$\delta e = -\ 0.00361$.
$\delta K = -\ 0.086$.
$\delta V = +\ 0.1727$ kilometers.

The substitution of these values in the equations of condition gives 1.72 as the greatest residual and 11.411 as the sum $[pvv]$. In the final ephemeris, however, the combinations of observations were discarded and the velocity computed for each of the thirty-one observations. The corresponding residuals are shown in column 5, the greatest being 1.70. It was found, as might be expected, that the sum $[pvv]$ obtained in this way is considerably greater than that obtained from the equations of condition. This is because in each of the four combinations the two observations fall on opposite sides of the curve, so that twice the square of the mean residual is much less than the sum of the squares of the two residuals. Accordingly, the greater value of the sum, 13.988, was used in computing the probable errors.

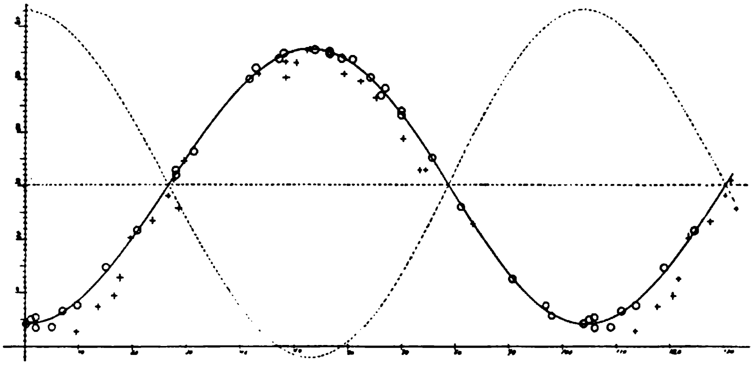
The sixth column of the table shows the difference between the residuals given by the final ephemeris and those given by the several equations of condition. It is inserted merely to show how far the neglect of second powers in the equations of condition is justified. In those cases where two observations are combined, the velocity for the mean date was not computed directly, but was assumed to be the mean of the two velocities, an assumption justified by the close proximity of the two dates in each of these cases.

The probable error of a single observation is ± 0.50 kilometer per second. The final values of the elements, with their probable errors, are given below:

$\omega = 117^{\circ}.3 \pm 18^{\circ}.3$.
$\mu = 0.060403 \pm 0.000014$ radians.
$= 3^{\circ}.46082 \pm 0^{\circ}.00081$.
$T = -\ 17.4 \pm 5.3$ days, the actual date being September 1.5, 1899.
$e = +\ 0.0164 \pm 0.0055$.
$K = 25.76 \pm 0.12$.
$U = 104.022$ days $\pm\ 0.024$ days.
$a \sin i = 36{,}847{,}900$ kilometers.
$V = +\ 30.17 +\ 0.104$ kilometers per second.

The great uncertainty in the values of ω and T is due to the fact that the orbit is so nearly circular. The probable errors of the other quantities are small in view of the difficulty of measuring the spectrum of this star.

The computed velocity-curve is shown in the diagram, abscissæ representing times (taking September 18.9, 1899, as the epoch), and ordinates the corresponding velocities in the line of sight. The points marked by circles represent the thirty-one observations from which the elements were computed. Mr. Newall's observations are also plotted, and are marked by crosses. It will be noted that of his twenty-three observations, two fall on the curve, two very slightly above it, and the remaining nineteen below it, generally several kilometers below. His observations would be fairly well represented by the elements here given if the quantity V were made somewhat smaller.



The dotted line parallel to the time-axis represents V, the velocity of the center of mass.

The dotted curve represents roughly the radial velocity of the lesser component of the system. Its orbit would differ from that of the principal component only in the value of a (or, what is the same thing, in that of K), and in ω, which would differ 180° from the ω of the principal component.

At any moment the line-of-sight velocities of the two components relative to their center of mass would be in a constant ratio; that is,

$$\frac{V_1 - V}{V_2 - V} = \frac{K_1}{K_2} = \frac{-a_1}{a_2} .$$

No very satisfactory determinations of the lesser component's velocities are at hand, but a few measurements have been made of sufficient accuracy to assign to the above ratio the approximate value of — 1.26, and the dotted curve was plotted on this basis.

By carrying back the period of 104.022 days to 1888 and 1889, the observations of Vogel and Scheiner can be compared with the orbit. It is found that their plate numbered 19 was taken at a time when the relative velocity of the two components was about zero. This plate they marked "excellent." Four other plates, numbered respectively 14, 15, 18, and 67, and marked "very good," "good," etc., were taken at times when the velocity of the solar component relative to the center of mass was 9 kilometers or less. One plate, numbered 95, is marked as rather poor except for a good $H\gamma$ line, although the velocity of the solar component relative to the center of mass was only 6 kilometers. With this exception, all plates marked "verwaschen," "uncertain," etc., were taken when the relative velocity of the two components was very large and therefore the two spectra were very much separated, so as to cause a blurring of the composite spectrum.

The preceding results enable us, with the assistance of micrometer observations, to set a limit to the value of the parallax of *Capella*.

Let a = distance apart of the two components ;
D = distance of *Capella* from the Sun ;
R = mean radius of the Earth's orbit ;
s = maximum angular separation of the two components ;
p = the parallax.

Then $\frac{a}{D} = s$

and $\frac{R}{D} = p;$

for $\frac{a}{R} = \frac{s}{p},$

or $p = \frac{Rs}{a}.$

If we make $a \sin i = 83{,}000{,}000$ kilometers, and $R = 149{,}000{,}000$ kilometers, we shall have

$$p = \frac{149}{83} s \sin i.$$

Messrs. W. J. Hussey, R. G. Aitken, and C. D. Perrine, of this observatory, report that on the most favorable nights they have been unable to see any certain elongation of *Capella* with the 36-inch telescope. Consequently it is reasonable to say that s cannot be so great as $0''.06$, for such a separation would certainly be detected if it existed.

If we give sin i its maximum value, unity, we have the relation

$$p < 0''.06 \times \frac{149}{83} = 0''.11.$$

H. M. Reese.

July 25, 1901.

OBSERVATIONS OF THE SPECTRUM OF *NOVA PERSEI*.[1]

At the time of the discovery of *Nova Persei*, the two single-prism spectrographs, with which all our low-dispersion photographs of the past ten years were secured, had just been shipped to Sumatra with the Crocker Eclipse Expedition. This shipment, including likewise several minor pieces of apparatus, left the spectroscopic resources of the observatory temporarily inadequate for the efficient analysis of the star's light. The Mills spectrograph was too powerful for a qualitative study of the spectrum, and was limited in its action to parts of the blue and violet regions. Fortunately, we possess an abundant supply of large 60° prisms, both light and dense; and from these, in connection with the Mills spectrograph, new and efficient apparatus was designed and constructed as required.

In all the spectrographs employed, and described below, the collimator section of the Mills spectrograph was used; and the changes made relate entirely to prism boxes, cameras, and braces for supporting the cameras. It will be a convenience in the discussion of the observations to have some ready method of referring to the different combinations of apparatus.

The Mills spectrograph, as ordinarily employed, will retain its usual designation.

The other instruments, referred to as spectrographs I, II, III, and IV, will now be described.

I. A brass prism box, designed some years ago by Mr. Campbell, for converting the Mills spectrograph into a one-prism instrument, was made ready for use by the evening of February 25. It contained a single 60° light flint prism, and carried the regular Mills camera of 406 mm focal length. The instrument was found to give excellent definition from above λ 3700 to λ 5700. By tilting the plate slightly, the definition was equally good from λ 4000 to λ 6000.

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[1] From *Lick Observatory Bulletin* No. 8.

II. A large 60° dense flint prism, and a visually corrected triple lens of aperture 5 cm and focal length 53 cm, were mounted in wood, and attached to the collimator section of the Mills spectrograph. Most of the visual observations, and some photographs in the yellow and orange regions, were secured with this instrument. It replaced spectrograph I late in the evening of February 25, and visual observations were obtained. The fine dark D sodium lines in the broad bright D band were seen at once, and with ease. The dark lines were compared directly with the bright D lines from an alcohol flame; and the star's lines were estimated by the two observers, respectively, to be displaced to the red about an eighth and a tenth of the distance between D_1 and D_2. These estimates — corresponding to radial velocities of 38 and 30 kilometers per second — were in close agreement with the photographic results [see page 51] secured a few nights later.

III. It was considered very desirable to obtain high-dispersion photographs of the D region. As the Mills spectrograph is limited to portions of the blue and violet, it was necessary to construct another prism box, and some auxiliary apparatus to secure the desired result. A prism box to hold three very dense 60° prisms was constructed of wood by the observatory carpenter, from designs by Mr. Wright. The whole matter of designing, constructing, adjusting, and testing the apparatus required a day and a half. The instrument gave excellent results; no effects of flexure or shrinkage of the wood during the long exposures were visible. With the 406 mm camera, the separation of the D lines is 0.15 mm.

IV. Another box, similar in design to the one described in the preceding paragraph, was constructed for the purpose of photographing the H and K region under high dispersion. It was lighter in some of its parts, and gave evidence of flexure. Results of value were secured with it, however. The three Mills prisms were used in this box, as the denser ones were entirely too yellow for work in the violet.

The comparison lines used include those of iron, magnesium, sodium, hydrogen, and helium. Wave-length determinations have in all cases been based on the Hartmann-Cornu formula.

The spectrum was recorded from $H\delta$ to $H\beta$ on February 24, with

PLATE XII

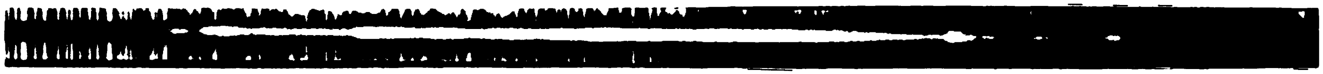

Fig. 1

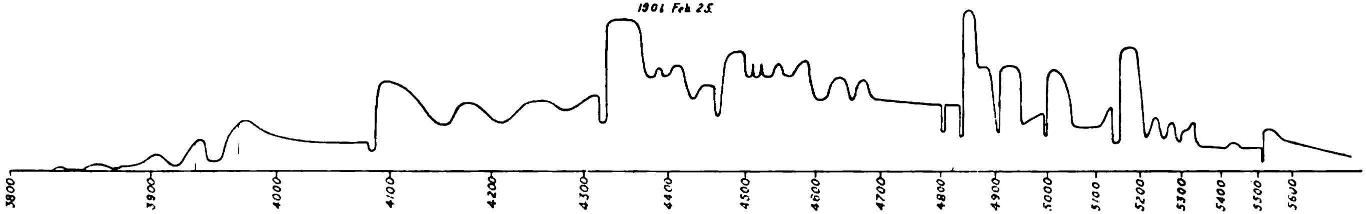

Fig. 2

Fig. 1.—*Nova Persei*, enlarged 7-fold. 1901, February 25.
Fig. 2.—*Nova Persei*, intensity curve. 1901, February 25.

the Mills spectrograph. The *Hδ*, *Hγ*, and *Hβ* bands of hydrogen were bright, and extremely broad, and were accompanied on their violet sides by very broad absorption bands. Otherwise the spectrum appeared to be strictly continuous. The absorption in the dark bands was only partial, so that the contrasts between bright and dark bands were very slight. The *Hβ* bands were easily visible, but the *Hγ* and *Hδ* bands were rather difficult, as a result of the too strong dispersion afforded by this instrument. The general character of the spectrum would have been shown much better by one-prism spectrograms.

On February 25, photographs were secured with spectrograph I, and the star was observed visually with spectrograph II. Numerous bright and dark lines were easily observed; and while allowance must be made for the lower dispersion used, it is safe to say that in the region of the spectrum photographed on the preceding night, the bright bands, and the contrasts between bright and dark bands, were relatively much stronger. The bands appeared to be identical with those in the early spectrum of *Nova Aurigae* (February, 1892), but in the earlier star the bands were much narrower, and the contrasts were vastly stronger.

Hα was very bright, and situated with reference to the artificial *Hα* line in the same manner as the other hydrogen bands with reference to their normal positions. It was accompanied on the more refrangible side by its corresponding dark band. A very bright and broad band in the orange, presumably due to sodium radiations, was crossed by two apparently monochromatic dark lines. These were identified as D_1 and D_2. To the violet of this band was the usual absorption. It covered the normal position of D_3, but there is no reason to suspect that it related to the element helium. Besides the five well-known *Nova* bright bands in the region of λ4860 to λ5270 no further details could be observed visually, on account of the strong continuous spectrum, which masked the fainter bands.

The spectrograms obtained on February 25 extend from λ3830 to λ5700. One of these, enlarged sevenfold, is reproduced in Plate XII, Fig. 1. Immediately below the reproduction is an intensity curve, Fig. 2, drawn after a comparison of all the plates of the evening. The results of the measurements of two of the plates are contained in Table I.

TABLE I.

February 25.		Description.		
2024 D.	2026 D.			
	λ 3829 3840	Very faint bright band.		
	3834.4	Suspected dark line.		
	3851 3862 3871	Max. Bright band.		
	3917	Minimum of broad absorption band.		
	3933.80	Strong dark line (K).		
	3939	Maximum of bright band.		
	3952	Minimum of broad absorption band.		
	3955	Beginning of bright band.		
λ 3968.54	3968.31	Rather faint dark line (H).		
	3989	End of bright band.		
4078 4086	4081 4087	Slight absorption.		
	4094	Bright band.		
4141		Bright band.		
4155 4174 4198	4158 4172	Max. Bright band.		
	4211	Minimum.		
4217 4274	4218 4270	Bright band.		
	4277	Minimum.		
4308		Slight maximum.		
4316 4324	4318 4326	Absorption.		
4335 4367	4376	Max. Bright band.		
4382		Beginning of bright band.		
4387		Slight maximum.		
4404 4416		Slight maximum.		
4418		End of band.		
4429		Minimum.		
4432	4442	Maximum.		
4459 4466	4450	Minimum.		
4470 4480		Maximum double (?).		These maxima make up a broad band.
4497		Maximum.		
4510		Very narrow maximum.		
4543 4555	4553	Max. v. f.	Brightening.	
4569 4587	4584	Max. f.		
4591				
4626	4626	Maximum of diffuse bright band.		
4667	4672	Maximum of very faint bright band.		

TABLE I.—*Continued.*

February 25.		Description.	
2024 D.	2026 D.		
4687	4690	Suspect minimum.	
	4803.0	Broad absorption line.	
	4808.2		
	4833.7	Broad absorption line.	
	4840.6		
4854	4853	Max. Bright band.	
	4905		
	4918	Maximum of bright band.	
	4951	End of bright band.	
	4992.7	Broad absorption line.	
	5000.1		
	5015	Maximum of bright band.	
	5051	End of bright band.	
	5111	Beginning of brightening.	
	5138	Absorption band.	
	5152		
	5179	Maximum of bright band.	These maxima make up a bright band.
	5213.9	Minimum.	
	5231.8	Maximum.	
	5255.1	Minimum.	
	5272.6	Maximum.	
	5294.8	Minimum.	
	5305	Suspect slight maximum.	
	5326	Maximum.	
	5337	End of band.	
	5409	Bright band, v. faint.	
	5443		
	5509	Rather narrow dark line.	
	5511	Bright band.	
	5523	Max.	
	5566		

Perhaps the most striking features of the plates are the broad, bright and dark H and K bands, the bright components being crossed by fine dark H and K lines. The band at H is evidently the result of the superposition of the *H*ε (hydrogen) and H (calcium) bands. The fine H line is apparently not so black as the K line, though allowance must be made for the different densities of the negative at the two places.

The violet edges of the bright bands are the more sharply defined, except for the K band, in which the reverse is the case. The hydrogen bands are very broad and diffuse, and it is difficult to locate the positions of maximum with accuracy. There seems, however, to be a decided shift of the maxima to the violet of the normal positions of the hydrogen lines, by an amount greater than the probable error of measurement. In the following table the first column contains the normal positions of the hydrogen lines, the second and third the observed positions of maxima taken from Table I, and the fourth the displacement of the maxima in tenth-meters:

λ (normal).	λ in Star.		Δλ.
4102		4094	−8
4341	4335		−6
4862	4853	4853	−9
			−8

The next photographs with the same apparatus were secured on March 15, by which time the spectrum had greatly changed. These changes appear to be more pronounced in the photographs taken on March 18 (Plate XIII), and these two sets will be considered together. The results of the measures are contained in Table II.

TABLE II.

March 13.	March 18.	Description.
2049 C.	2057 D.	
λ 3866.79		Narrow dark line.
3869.87	λ 3870.0	Narrow dark line.
3878	3874	
3896	3892	Maximum } Bright band (*H*ζ).
3912	3910	
3933·89	3933·67	Fine dark line (K).
	3945	Apparent beginning of bright band.
3945·2	3945·7	Fine dark line.
3946.9		Fine dark line.
3950·37	3950.16	Strong dark line. Width in 2057 D = 0.9 t. m.
3968.40	3968.62	Narrow dark line (H).
3974	3975	Maximum of bright band (*H*ε).
3987	3991	End of band.
	4068	Beginning of bright band.
4075·3	4074·6	Dark line.
4078.0	4077·4	Dark line.
4081.35	4081.32	Strong dark line. Width in 2057 D = 1.3 t. m.
4105	4108	Maximum of bright band (*H*δ).
4128	4131	End of band.
	4171	Maximum of very faint bright band.
	4219	} Very faint bright band.
	4244	

PLATE XIII

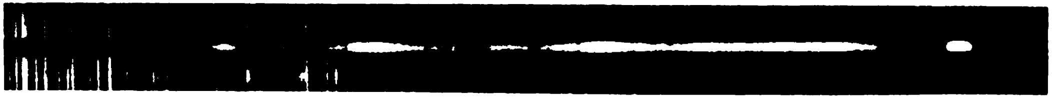

FIG. 3

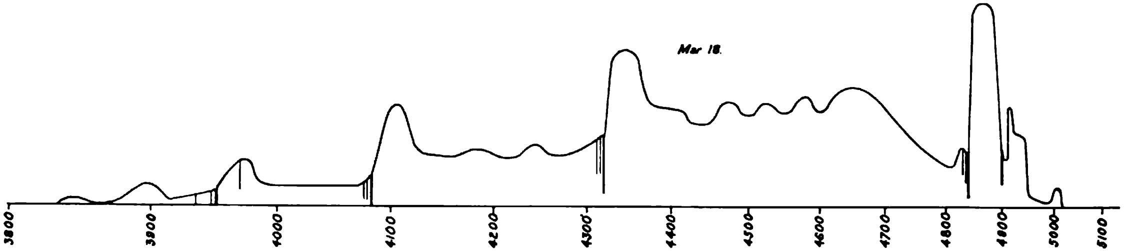

FIG. 4.

Fig. 3.—*Nova Persei*, enlarged 7-fold. 1901, March 18.
Fig. 4.—*Nova Persei*, intensity curve. 1901, March 18.

TABLE II.—*Continued.*

MARCH 13.	MARCH 18.	Description.
2049 C.	2057 D.	
	4303	Beginning of bright band.
	4310.2	Faint fine line.
4312.7		Faint fine line (suspected).
4315.0	4314.2	Faint fine line.
4318.42	4318.55	Strong, well-defined dark line. Width in 2057 D = 0.9 t. m.
4342	4347	Maximum of bright band ($H\gamma$).
4366	4368	End of band.
	4454 4490	Very faint and diffuse bright band.
	4515	Maximum of suspected bright band.
	4820	Beginning of bright band.
	4826	First maximum of bright band.
	4828	Suspect dark line.
	4832.7	Faint dark line.
4835.0	4836.5	Strong dark line. Width = 1.9 t. m.
4862	4868	Maximum of bright band ($H\beta$).
4907	4900	Beginning of bright band.
4916	4914	Maximum.
4946	4943	End of band.
5015	5005 ±	Maximum of bright band, just visible.

The spectrograms of March 13 show the K band to have disappeared. Most probably the H band shared a similar fate, though it is impossible to prove this, on account of the superposition of the $H\epsilon$ band referred to above. The fine H and K lines remain, but the absorption in the former appears to be less complete than before. The maxima of the bright hydrogen bands are shifted toward the red from the normal positions of the hydrogen lines. The amount of this shift, taken from Table II, is as follows :

Line.	$\Delta\lambda$.	
	March 13.	March 18.
$H\zeta$	+7 t. m.	+3 t. m.
$H\epsilon$	+4	+5
$H\delta$	+3	+6
$H\gamma$	+1	+6
$H\beta$	+1	+7
(Means)	+3	+5

The bands are so diffuse that the position of maximum in any one case is uncertain to the amount of several tenth-meters. It is certain, however, that there is a displacement in the direction mentioned.

It is in the dark bands accompanying the bright ones that the changes are most marked. The former broad, diffuse absorption bands are replaced by multiple fine lines. Of these lines, the one of greatest wave-length is many times the most intense, and practically terminates the bright band with which it is associated. Two other lines were observed with certainty in many of the groups, and were suspected in all the groups, except *H*ζ, where the spectrum was too faint for reliable observation.

The displacements of the principal dark lines from the normal positions of the hydrogen lines vary considerably from one end of of the spectrum to the other, but seem to be very approximately proportional to the wave-lengths. In the following table the means of the displacements for the two dates are given in the second column, while those computed on the assumption of direct proportionality to the wave-lengths are given in the third. The assumed proportion is represented by the equation $\Delta\lambda = 0.00505\ \lambda$.

Line.	$\Delta\lambda$.		O—C	Weight.
	Observed.	Computed.		
Hζ	19.28 t. m.	19.64 t. m.	−0.36 t. m.	1
Hϵ	20.04	19.98	+0.06	1
Hδ	20.51	20.79	−0.28	1
Hγ	22.18	22.91	+0.27	1
Hβ	25.7	24.5	+1.2	½

The wave-lengths in the neighborhood of *H*β cannot be determined with great accuracy from these plates, on account of both the relatively low dispersion in that region of the spectrum, and the unsatisfactory nature of the comparison lines available for measurement. In the determination of the constant of proportionality the *H*β result was therefore given weight one-half. Considering the unsymmetrical distribution of light on the two sides of the absorption lines, it is safe to say the residuals (O—C) are commensurate with the errors of measurement. The proportionality of the displacements of the dark hydrogen lines to their wave-lengths therefore appears to be a fundamental characteristic of the star's spectrum at this stage of its development.

We shall refer to the displacements of some of the other dark lines, the origins of which are open to little doubt. While the dark H and K bands were in evidence, they were displaced toward the more refrangible end of the spectrum by about 16.5 t. m. On account of the breadth of the bands, the measured displacement is liable to an error of perhaps two tenth-meters. The displacement computed by means of the proportionality assumed above is 20 t. m. The displacement of the dark D band (due to sodium), which will be referred to below, is 27 t. m. The error of measurement of the position of this band is influenced by its breadth, and to some extent by the sensitiveness curve of the "isochromatic" plate used, which is very steep in this region of the spectrum. The tendency would be to make the measured displacement smaller. The computed displacement is 30 t. m.

The computed displacements given above depend, as has been said, on measurements of the fine hydrogen lines which developed after the calcium bands had disappeared, and probably after the spectrograms of the D band had been secured. It might therefore seem more reasonable to compare the displacements of the calcium and sodium bands with those of the diffuse bands of hydrogen which existed simultaneously with them, and resembled them somewhat in their general characteristics. The displacements of the hydrogen bands are:

Line.	$\Delta\lambda$.
$H\delta$	−19 t. m.
$H\gamma$	−19
$H\beta$	−24

From these we obtain the equation $\Delta\lambda = 0.0046\,\lambda$. The observed displacements, and those computed on this basis, are:

Line.	$\Delta\lambda$.	
	Observed.	Computed.
K	−17 t. m.	−18 t. m.
H	−16	−18
D	−27	−27

The agreement is closer than that resulting from the first assumption. There is then no evidence that the position of the bands is affected by other considerations than that of wave-length.

The other features of the spectrum are shown in the reproduction of one of the plates of March 18, Plate XIII, Fig. 3, directly enlarged from the original negative; and still better by the intensity curve subjoined Fig. 4.

The drawings of the intensity curves for February 25 and March 18 are not strictly comparable on the red side of $H\beta$, for the reason that the plates used on the two dates were of different character. The earlier spectrogram was made on a Cramer Isochromatic plate, and the late one on an ordinary Cramer Crown, a plate not sensitized to the lower rays. The isochromatic plate is of reduced sensitiveness in the region λ 4800 to λ 5400; and in constructing the intensity curve the observer increased the ordinates in this region somewhat arbitrarily, but in accordance with his judgment. In all of the plates secured on March 13 and 18, the region λ 4600–λ 4700 was over-exposed, and the details thereby destroyed.

During the early part of April the appearance of the spectrum was as is indicated in Plate XIV, Figs. 5 and 6, and in Table III. The triple absorption lines referred to above had so decreased in intensity as to make their recognition very uncertain. A broad and diffuse absorption had developed in the neighborhood of the normal position of the three principal hydrogen lines. $H\zeta$ is just on the limit of visibility on the photographs, and no details can be observed with certainty in that region. The spectrogram of April 5 was made on a Cramer Isochromatic plate, as was also that of February 25, so that the two should be comparable.

It was not possible to observe the star every night over a long period of time, for the purpose of detecting rapid variations in the spectrum: such ones, for instance, as might accompany the more or less periodic changes in the star's brightness. In general, it was noticed during the spring months that the bright bands were relatively more intense at minima than at maxima of the star's brightness; that is, that the variations affected the continuous spectrum more than the bright lines. We recognize that physiological effects may play an important part in such estimates, however. Definite changes certainly occurred between April 1 and 5. The bands λ4629 and λ4675, appearing on the spectrogram of April 5, are not on that of April 1; and the bands of April 1 at λ4583 and λλ4632–4661 are not recorded on that of April 5. The band at λ4675 was too faint to record itself on the earlier photograph. The changes described could be caused by variations in the relative intensities of one or two of the bands concerned.

PLATE XIV

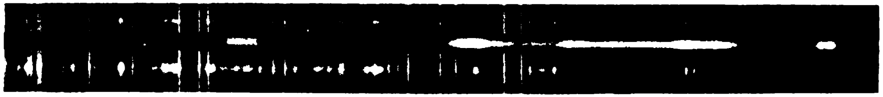

FIG. 5

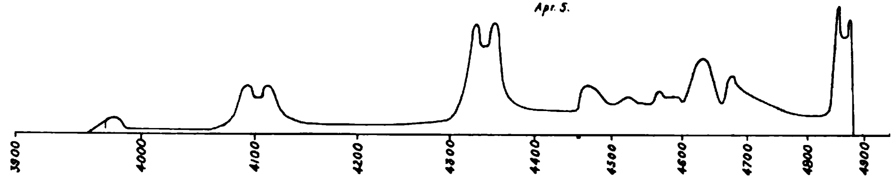

FIG. 6

Fig. 5.—*Nova Persei*, enlarged 7-fold. 1901, April 5.

Fig. 6.—*Nova Persei*, intensity curve. 1901, April 5.

TABLE III.

APRIL 1.	APRIL 5.	Description.	
2064 D.	2067 D.		
λ3956	λ3959	v. f. bright band (*Hε*)	
3986	3982		
3968.1	3968.5	Dark line, very poor (H).	
4079	4079		Bright band (*Hδ*).
4097	4097	Diffuse absorption, very faint.	
4103	4109		
4126	4126		
4318	4317		Bright band (*Hγ*).
4335	4337	Diffuse absorption, very faint.	
4340			
4344	4349		
4365	4368		
4457	4456	Bright band.	
	4461	Max.	
4492	4489		
	4523	Center of very diffuse bright band.	
4508		Suspected v. f. bright band.	
4536			
	4555	Maximum of rather faint bright band.	
	4562		
4583		Maximum of suspected faint bright band.	
	4600	Suspected minimum.	
	4607	Bright band.	Identical (?)
	4629	Max.	
	4660		
4632		Bright band.	
4661			
	4667	Bright band.	
	4675	Max.	
	4683		
4699		Max. of v. f. bright band, just visible.	
4847	4837		Bright band (*Hβ*).
	4855	Diffuse absorption, v. f. and uncertain.	
	4861		
	4869		
4881	4882		

The absence, in Sumatra, of the principal parts of the large visual spectroscope, prevented visual measurements of the spectrum. There was little need for these, however, as the isochromatic plates afforded vastly more valuable observations down to and including the D region; and the *Hα* band was photographed with erythro plates, as well as observed visually. In February no bright bands were visible except those which have been mentioned above, or described in the tables. As the star grew fainter, additional bands were observed. At the times of the last visual observations, on April 14 and 21, essentially all the bands observed in the early spectrum of ***Nova Aurigae*** were present. Those at λ5760, λ5840, λ6160 and λ6300 were easily seen. The last photographic observation was secured on April 14.

The spectrum was observed visually on two evenings, with instrument I, for the purpose of determining whether the light of the star was polarized in any manner. The slit was opened wide, and a Nicol prism was held in front of the eyepiece. As the prism was rotated, no narrowing of the lines, or other phenomena, were observed, except a slight darkening of the spectrum as a whole, due to the polarizing effect of the spectroscope. The results furnish no evidence of a Zeeman effect in the star, but in some respects the evidence is merely of a negative character.

The velocities in the line of sight determined from measurements of the fine dark H and K calcium lines on all the plates secured up to and including March 18, with spectrograph I, are contained in the following table:

Date.	Plate No.	Velocities.	
		H.	K.
February 25...	2023 C	− 4 km	+ 6 km
	2025 C	+ 2	+ 5
	2026 D	....	+ 13
March 13. ...	2049 C	− 6	+ 13
	2050 D	+ 22	− 4
March 18.....	2056 C	....	+ 14
	2057 D	+ 7	+ 7
	Means	+ 4.2	+ 7.7

These values are corrected for the orbital motion of the Earth, but not for diurnal motion and the curvature of the spectrum lines. These corrections are −0.2 km and −0.3 km respectively. Applying them to the mean of the individual determinations, we have +5.7 km per second as the observed radial velocity of the star. This value was used in correcting all the wave-lengths determined with spectrograph I.

Recalling that the above individual results depend each upon measures of a single line, on plates secured with an instrument containing only one light flint prism, whereas the current results with the Mills spectrograph depend upon measures of many lines dispersed by three dense flint prisms, the linear values of the discrepancies are seen to be small.

A spectrogram of the H and K region secured on March 5 with spectrograph IV yielded the following velocities, from the fine dark lines:

H, + 6.5 km
K, + 8.1

Means, + 7.3

A discrepancy of 2.5 km at *H*γ corresponds in linear value to 1.8 km at H.

These dark lines were very narrow. Their measured widths on the above plate were 0.22 t. m. and 0.28 t. m., respectively, including the effects of flexure of the instrument in broadening the lines.

Plate XV, Fig. 9 is a reproduction of the H and K region recorded with spectrograph I on February 25.

Spectrograms of the D region were secured on February 26, 27, 28, March 3, 14, and 17, with either low or high dispersion. While some of the low dispersion plates are quite satisfactory, those of high dispersion are so much more so, that results from the high dispersion alone will be considered. Two of the latter were obtained on February 28 and March 3. Reproductions of them are given in Plate XV, Figs. 7 and 8, respectively. The position of maximum is apparently to the violet of the D absorption lines; but the slope of the sensitiveness curve of the plate, referred to above, would have a very strong tendency to shift the apparent maximum to the violet, so that it is impossible to locate the actual position of greatest intensity.

The radial velocities of the *Nova* determined from the D lines on these plates are as follows:

Date.	Plate No.	Velocity.		Mean.	Corr. for Curv.	Red. to Sun.	Velocity.
		D_1.	D_2.				
Feb. 28 ..	2034 C	+ 38.7	+ 33.8	+ 36.1	− 2.7	− 27.3	+ 6.1 km
Mar. 3 ..	3040 D	+ 33.8	+ 25.8	+ 29.8	− 2.3	− 27.0	+ 0.5
			Mean velocity with reference to Sun....				+ 3.3 km

In comparing these results for the D region with those secured from ordinary line-of-sight work in the violet region, it is necessary to bear in mind the matter of relative prismatic dispersion for the two regions. In the Mills spectrograph work at $H\gamma$, we should be satisfied if the discrepancy between the values secured from two plates, on each of which only two lines had been measured, were less, say, than 2½ kilometers per second. The linear value of the discrepancy between the above results, $6.1 - 0.5 = 5.6$ km, would correspond to 2.4 km at $H\gamma$ with the Mills spectrograph.

As a check on these results, the D lines were measured on a spectrogram of the planet *Mars*, taken under similar conditions. The difference between the observed and computed velocities, -2.2 km corresponds to -1.0 km at $H\gamma$, and is satisfactory.

The D absorption lines are very narrow. A comparison of their widths with those of the corresponding lines in the solar spectrum is not without interest. A measurement of one of the plates places their width at 0.8 t. m. The width of the solar lines according to Rowland's tables is 0.17 t. m. It was considered better, however, to compare the two spectra under the same instrumental conditions. The widths of the D lines on a spectrogram of *Mars* and on one of the Sun were therefore measured, with the following results:

Line.	*Mars.*	Width in Sun.	*Nova.*
D_1	1.0 t. m.	0.9 t. m.	0.8 t. m.
D_2	1.2	1.1	0.8

The solar and planetary lines are probably somewhat broadened by the presence of unresolved companions, but it is evident that the breadths in the two cases are of the same order. The last spectrogram of the D region, secured in the spring, was a low dispersion one taken on March 17. It showed the general features to have remained practically unchanged.

For convenience, the determinations of radial velocity referred to above are here collected:

Spectrograph I, H and K, + 5.7 km
Spectrograph III, D_1 and D_2, + 3.3
Spectrograph IV, H and K, + 7.3

In addition to the spectrograms on which these results depend, a number of others recorded the absorption lines of sodium and

PLATE XVI

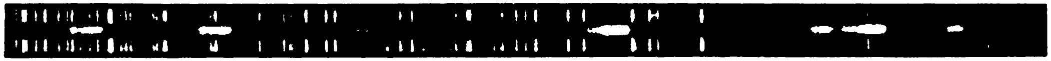

FIG. 10

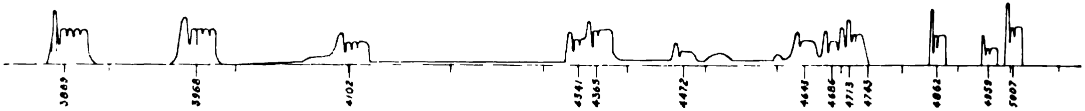

FIG. 11

FIG. 12

Fig. 10.—*Nova Persei*, enlarged 7-fold. 1901, July 15.
Fig. 11.—*Nova Persei*, intensity curve. 1901, July 15.
Fig. 12.—*N. G. C.* 7027, enlarged 7-fold. 1901.

calcium. Within the limits of error of measurement, all give accordant results. There is no evidence that the velocity is variable; and this view is strongly confirmed by the results of the summer series of observations, to be described below.

Spectroscopic observations of *Nova Persei* were discontinued from April 21 to July 9, while the Sun was passing through this region of the sky. Our regret that the southern position of the Lick Observatory prevented observations in this period is coupled with the hope that the observatories of northern Europe were able to obtain a practically continuous series.

Our summer series of observations has been secured mainly with spectrograph I. The first observation of the series was made on July 9. As announced by Professor Pickering, the spectrum at this time was that of a nebula. The usual nebular lines are represented by broad bright bands. The several spectrograms obtained at well-distributed intervals since July 9 do not show that any pronounced changes have occurred in this time. The results of the measurements of four of the plates are contained in Table IV. An ordinary plate, No. 2198C of July 15, and an isochromatic plate, No. 2223D of August 11, with their corresponding intensity curves, are reproduced in Plate XVI, Figs. 10, 11, 13, and 14, respectively.

TABLE IV.

July 15. 2198 C.	July 16. 2199 D.	July 24. 2205 E.	August 11. 2223 D.	Description.
λ 3855	....	λ 3854	....	Beginning of bright band.
3858.3	....	3858.3	....	Absorption line.
3860.3	....	3860.1	....	Maximum of bright band.
3864.0	....	3864.2	....	Broad absorption line.
3869.7	....	3869.7	....	Broad and hazy absorption line.
3874.9	....	3875.0	....	Absorption line.
3878.9	....	3879.0	....	Absorption line.
3885	....	3885	....	End of brighter part of band.
....	....	3890	....	End of band.
....	....	3947	....	Beginning of bright band.
3953	....	3953	....	Beginning of brighter part of band.
3959.1	....	3959.0	....	Maximum of bright band.
3962.6	....	3962.8	....	Broad absorption line.
3968.64	...	3968.71	....	Strong and narrow absorption line (H).
3971.4	....	....	....	Suspect absorption line.
3984	....	3984	....	End of brighter part of band.
....	....	3988	....	End of band.
....	....	4056	....	Beginning of brightening.
4088	....	4084	....	Beginning of brighter part of band.

TABLE IV.—*Continued.*

July 15. 2198 C.	July 16. 2199 D.	July 24. 2205 E.	August 11. 2223 D.	Description.
4093.5	....	4093.9	....	Maximum of bright band.
4097.1	....	4097.2	....	Rather broad absorption line.
....	....	4108.5	....	Absorption line.
4118	....	4120	....	End of band.
4325	....	4324	....	Beginning of bright band.
4331.5	....	4330.9	....	First maximum.
4335.5	....	....	....	Rather narrow dark line, absorption incomplete.
4349	....	4348	....	Beginning of second brightening.
4353.2	....	4353.9	....	Second maximum.
4357.9	....	4358.2	....	Absorption line.
4364.6	....	4364.7	....	Diffuse absorption line.
4385	....	4381	....	End of brighter part of band.
		4390	....	End of band.
4456	....	4455	....	Beginning of bright band.
4462	....	4462.0	....	Maximum.
4466	....	4467.1	....	Absorption line.
....	....	4472.1	....	Suspect absorption.
4488	....	4489	....	End of band.
4497	....	4499	....	Beginning of faint diffuse bright band.
4523	....	....	....	Diffuse maximum.
4548	....	4549	....	End of band.
4557	....	....	....	Beginning of suspected faint band.
4561	....	4559	....	Maximum.
4568	....	....	....	End of band.
4590	....	4594	....	Beginning of faint brightening.
....	....	4600	....	Maximum.
4613	....	4609	....	End of brightening.
4615	....	4618	....	Beginning of bright band.
4623	....	....	....	Suspect faint maximum.
4632	....	....	λ 4631.2	Principal maximum.
4635	....	....	4633.8	Absorption line.
4661	....	4656	4656	End of band.
4669	....	4670	....	Beginning of bright band.
4676	....	4675.5	4675.4	First maximum.
4681	....	4680.5	4680.6	Absorption line.
4689	....	....	4687.0	Absorption line.
4696	....	4695.7	....	Absorption line.
4698	....	4698	4698.1	Beginning of what is evidently a superposed band.
4703	....	4702.3	4703.0	Second maximum.
4708	....	4707.9	4708.7	Hazy absorption line.
4714	....	4713.2	4713.8	Third maximum, stronger than preceding ones.
....	....	4717.8	4719.5	Absorption line.
....	....	....	4725.7	Absorption line.
4736	....	....	....	Absorption line.
4748	....	4745	4742	End of band.
4845	....	4846	4846	Beginning of band.
4849	....	....	....	Absorption line.
4852	....	4853.2	4850.0	Maximum.
4856	....	4855.7	4854.8	Absorption line.

TABLE IV.—*Continued.*

July 15. 2198 C.	July 16. 2199 D.	July 24. 2205 E.	August 11. 2223 D.	Description.
4862	....	4862.7	4862.1	Absorption line.
4869	....	....	4868.4	Absorption line.
4873	....	....	....	Suspect absorption line.
4880	....	4879	4878	End of band.
4945	....	4944	4942	Beginning of bright band.
4948	....	4947.7	4946.8	Maximum.
4954	....	4952.2	4952.6	Absorption line.
4961	....	4960.3	4959.0	Absorption line.
4968	....	....	4966	Suspect absorption line.
4976	....	4979	4978	End of band.
4989	....	4990	4987	Beginning of bright band.
4992	....	....	....	Suspect absorption line.
4996	....	4995.4	4994	Maximum of bright band.
5001	....	5000.6	....	Absorption line.
5008	....	5008.2	....	Absorption line.
5016	....	....	....	Suspect absorption line.
5027	....	5026	5027	End of band.
....	λ 5038	....	....	Absorption line.
....	5040	....	5039	Faint bright band,[1] which possibly runs back to preceding band.
....	5049	....	....	maximum
....	5067	....	5070	
....	5136	....	5137	Bright band.[1]
....	....	....	5168	maximum
....	5201	....	5199	
....	5264	....	5259	Bright band.[1]
....	5297	....	5298	maximum
....	5312	....	5317	
....	5389	....	5393	Bright band.[1]
....	5414	....	....	maximum
....	5433	....	5438	
....	5513	....	5513	Difficult bright band.[1]
....	5548	....	5562	
....	....	....	5603	Maximum of very difficult bright band, broad and diffuse.[1]
....	5652	....	5651	Bright band.[1]
....	5671	....	....	maximum
....	5713	....	5716	
....	5733	....	5735	Beginning of bright band.
....	5741	....	5741	Maximum.
....	5746	....	5747	Absorption line.
....	....	....	5764	Suspect absorption line.
....	5769	....	5770	Absorption line.
....	5778	....	5776	End of band.
....	5856	....	5857	Beginning of bright band.
....	5863	....	5862	Maximum.
....	5869	....	5867	Absorption line.
....	5877	....	5878	Absorption line.
....	5890	....	5890	Absorption line (D_2).
....	....	....	5895	Absorption line (D_1).
....	5896	....	5896	End of band.

---

[1] These bands are very diffuse. The determinations of wave-length are therefore uncertain to the extent of several tenth-meters.

The *Hα* band is very bright, but no other details additional to those on the photographs have been shown by the visual observations.

A striking feature of the spectrum is the distribution of the light in most of the bands. In general, there is a maximum, considerably displaced to the violet of the normal position of the nebular line. This maximum is accompanied on its less refrangible side by a pronounced minimum. In most cases another minimum appears to the red of this, and in some of the bands there are additional minima. The one nearest to the maximum is in each case the strongest. While we have, of course, no knowledge as to the origin of these minima, their appearance certainly suggests that they are absorption phenomena, and they will be referred to as such. Though most of the bands conform to a general type, they are not by any means duplicates of one another. In some cases the principal absorption line alone was identified with certainty, while in others lines apparently not belonging to the series were strongly suspected. In a number of instances the appearance of the bands was indicative of such complexity of structure as to make it impossible to consider more than their general features in a preliminary study of this sort. It is quite possible that some of the absorption lines are due to gases in the atmosphere of the star which are not directly involved in the production of the bands. In fact, this actually occurs in the case of the D sodium lines and the H calcium line. The latter appears as an absorption line in the band λ 3947–λ 3988. There is little reason to doubt that its companion, the K line, is absent only by reason of the fact that there the calcium vapor has nothing to absorb.

Another cause of complexity is the overlapping of bands. This occurs in at least three cases:

1. The bands corresponding to λ 4340.6 (*Hγ*) and λ 4363 (nebular line) are involved in the composite band λ 4325–λ 4385.

2. Those belonging to the nebular lines λ 4685.9 and λ 4713.2 (helium) are superposed in the band λ 4669–λ 4746. There are, in fact, circumstances which indicate the presence of still another component in this band. It will be seen by referring to Table IV that there is a maximum at λ 4714, brighter than the one at λ 4703, and which cannot be accounted for by the superposition of the two bands to which reference has been made, assuming them to be of normal type. In addition, there are absorption lines at λ 4719 and λ 4725.7. These effects would be produced by a superposed band of the regular

type corresponding to a line of normal wave-length λ 4724. Moreover, judging from the other bands, the band whose maximum is at λ 4703 should vanish at about λ 4733, whereas the composite band in question extends to λ 4746. The extension may, however, be due to the nebular line λ 4743 ±, the presence of which is partially indicated by an absorption line at λ 4736. While the complexity of the band is such that a final statement of its composition is impossible without further study, the hypothesis of a line normally at λ 4724 is advanced as furnishing a plausible explanation of the structure of the broad band.

3. The band λ 3953–λ 3984 was supposed at first to be the broadened *Hε* line; but on this supposition the line is unduly strong. The *Hγ* band is very bright, *Hδ* is fairly bright, and the λ 3969 is very bright, whereas *Hζ* and the rest of the ultra-violet hydrogen series do not appear. Furthermore, the displacement of the maximum of this band to the violet of the normal position of *Hε* was greater by about two tenth-meters than that of the other maxima in this region of the spectrum. Some spectrograms of well-known planetary nebulæ recently secured by Mr. Wright fully explain these peculiarities. In all previous work on the nebulæ, the line recorded at this point in the spectrum has been regarded as single, and has been assumed to be *Hε*. The line is in reality a wide double, as shown in the reproduction of the spectrum of *N. G. C.* 7027, Fig. 12. The component of greater wave-length is the *Hε* hydrogen line at λ 3970.2; it is very faint. The more refrangible component, at λ 3967.6, is much the brighter of the two, and appears to be a characteristic strong nebular line, not previously observed. The positions and relative intensities of these lines leave no doubt that the *Nova* band at λ 3453–λ 3984 corresponds almost entirely to this nebular line at λ 3967.6, and is scarcely influenced by the *Hε* radiations.

In order to investigate the displacements of the maxima of the star bands, from the normal positions of the lines in the nebulæ, it was found necessary to make more accurate determinations of the wave-lengths of some of the nebular lines than were available. An investigation with that end in view was therefore undertaken by Mr. Wright, and some of the preliminary results will be used in this paper. The following table gives the displacements of the maxima and of the absorption lines of all the bands of the *Nova* which have been identified as being of nebular origin. The first column contains the normal wave-lengths of the lines in nebular spectra, the second the displacements of the maxima, and the third the computed displacements on the assumption of proportionality of displacement to wave-length, according to the empirical formula $\Delta\lambda = -0.00212\,\lambda$. The following four columns contain the measured displacements of the absorption lines which appear to belong to the bands. Positive and negative signs indicate displacements toward the red and violet ends of the spectrum, respectively. Both the maxima and the minima appear to be displaced in proportion to their wave-lengths. The observed widths of the bands are given in the eighth column, as far as they can be determined; but it should be said that the photographic widths are affected both by their intensities and by the sensitiveness curve of the plate. The red edge of the band at λ 5876 is practically at the limit for isochromatic plates. The wave-lengths of the principal bright bands observed in *Nova Aurigae* in August, 1892 by Mr. Campbell are contained in the last column. That star was of 10.5 magnitude, and the photographs did not cover the ultra-violet regions.

TABLE V.

Wave-lengths in the Nebulæ.	Displacements.						Width of Bands.	Principal Bands *Nova Aurigae*.
	Max. Observed.	Max. Computed.	Min. Observed.	Min. Observed.	Min. Observed.	Min. Observed.		
3868.9	− 8.7	− 8.2	−4.8	+0.8	+6.0	+10.0	31	....
3967.6	− 8.6	− 8.4	−4.9	+1.1*	(+3.8)	.....	31	....
4101.9	− 8.2	− 8.7	−4.8	+1	+7	......	36	4098
4340.6	− 9.4	− 9.2	−5	......	......	......	..	4336
4363.3	− 9.7	− 9.1	−5.2	+1.4	......	......	33	4358
4471.6	− 9.6	− 9.5	−5	(0)	......	......	34	4466
4643±	−11	−10	−8	......	......	......	..	4630
4685.9	−10	−10	−5	+3	......	+10	..	4681
4713.2	−10	−10	−5	......	......	......	..	471—
4743	......	......	−6	......	......	......	..	....
4861.5	− 9	−10	−6	+1	(+7)	(+11)	33	4857
4959.0	−11	−11	−6	+2	......	......	34	4953
5007.0	−11	−11	−6	+1	......	......	38	5002
5752	−11	−12	−6	......	......	+16	43	5750
5875.9	−13	−12	−7	+1	......	......	40	....
6563†	......	......	......	......	......	......	..	....

* The dark line H falls in this place and determines the exact position measured.

† The very bright *Hα* band was observed visually, but no attempt was made to photograph it in the summer series.

Parentheses indicate that the line was only suspected. The absorption in most of the lines is incomplete, so that the bringing out of any particular one is largely a matter of exposure and development. It is quite possible that other lines exist which will appear in a final comparison of all the spectrograms secured.

The nebular character of the *Nova* spectrum at present is evident from the measures published in the tables, and may be seen at a glance by comparing Plate XVI, Figs. 10, 11, and 12. All of the principal bands correspond to lines known to exist in the nebulæ.

A comparison of the first and last columns of Table V shows that the spectrum of *Nova Aurigae* is very closely related to that of *Nova Persei.* The absence of the bands at λ 4743, λ 5876, and λ 6563 from the former star is no doubt explained by the fact that it was more than four magnitudes fainter than the present star; and it is probable that the bands at λ 3869 and λ 3968 were not recorded in 1892 because no auxiliary correcting lens was used to eliminate the chromatic aberration effects of the 36-inch objective. The bands in the present *Nova* are vastly wider than in that of 1892, and the distribution of light within the bands seems to be different. The positions of corresponding maxima differ about five or six tenth-meters in the two cases. Perhaps the most remarkable features of the 1892 spectrum were the bands observed by Mr. Campbell at λ 4358 and λ 5750. The λ 4358 band, in August, 1892, was estimated to be at least eight times as bright as the $H\gamma$ band; but in November, 1894 it had become fainter than $H\gamma$; and the band at λ 5750, so easily observed in 1892, had become extremely difficult in 1894 (ASTROPHYSICAL JOURNAL, 1, 49–51). These two bands are now very prominent in *Nova Persei,* and it is probable that they will diminish in brightness, as in the case of the earlier star. Corresponding to these two bands there are faint lines in the well-known nebulæ.

The radial velocity of *Nova Persei,* determined from the H absorption line of calcium, was + 6 km on July 15, and + 12 km on July 24. The mean of the two determinations is in satisfactory agreement with the value, 5 km, afforded by the H line in the spring series.

At the time of the spring observations the D absorption lines occupied positions near the middle of the broad D bright band, as shown in Figs. 7 and 8; and the D_3 comparison fell near the more refrangible edge of the band. In the summer observations, the D_3 comparison line, Fig. 13, falls near the middle of the bright band, and the sodium comparison lines are situated at the extreme red edge of the band. A long exposure made on August 12 records this bright band to about the wave-length λ 5902, and the sodium D absorption lines are clearly shown to be present. Within the limits of error of measurement they occupy exactly the same positions as in the spring observations. Corroborative evidence is thereby afforded that the radial velocity of *Nova Persei* has been practically constant.

It is well known, from the investigations of Runge and Paschen (ASTROPHYSICAL JOURNAL, **3**, 4), and others, that the spectrum of helium consists of two sets of lines, and that the relative intensity of the two sets varies with the pressure to which the radiating gas is subjected. Both sets are emitted by a Plücker tube under a few millimeters pressure. The first column of the following table gives the wave-lengths of all the helium lines between λ 3800 and λ 5900 described by Runge and Paschen as having an intensity equal to or greater than three on a scale of ten. The second column records the intensity. In the third column the Roman numeral I or II indicates that the line belongs to the low or high-pressure series, as the case may be. Each of the sets I and II is subdivided by Runge and Paschen into a principal, a first subordinate, and a second subordinate series. The two subordinate series are indicated by subscripts. The fourth column is self-explanatory.

λ.	Intensity.	Series.	Remarks.
3819.8	4	II_1	Not observed in *Nova*.
3888.8	10	II	Not observed in *Nova*.
3964.9	4	I	Conflicts with band λ 3855-λ 3885, but probably not in *Nova*.
4026.3	5	II_1	Not observed in *Nova*.
4120.9	3	II_2	Not observed in *Nova*.
4388.1	3	I_1	Not observed in *Nova*.
4471.6	6	II_1	Observed in *Nova*, fairly bright.
4713.2	3	II_2	Observed in *Nova*, bright.
4922.1	4	I_1	Not observed in *Nova*.
5015.7	6	I	Not observed in *Nova*.
5875.9	10	II_1	Observed in *Nova*, very bright.

It will be seen that the high-pressure series is the only one appearing in the new star, and that even of this series the more refrangible lines are lacking. The maximum of the line λ 3888.8 should lie just within the band λ 3855-λ 3885; but the helium band should extend to λ 3904 if it were present in any strength. It is a significant fact that both sets are present in most of the nebluæ, though their relative intensities vary considerably. The evidence of the helium lines would

PLATE XVII

FIG. 13

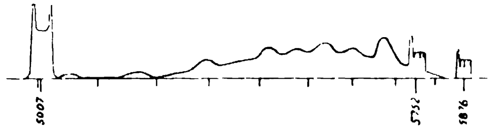

FIG. 14

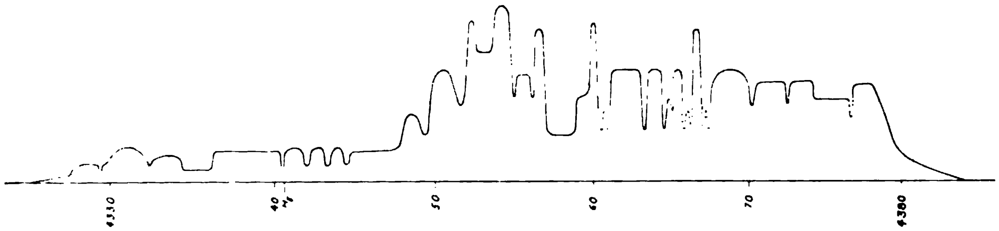

FIG. 15

Fig. 13.—*Nova Persei*, enlarged 8-fold. 1901, August 11.
Fig. 14.—*Nova Persei*, intensity curve. 1901, August 11.
Fig. 15.—*Nova Persei*, $H\gamma$ region, high dispersion. 1901, September 3.

seem to show that the radiation does not take place under exceedingly low pressure.

A number of the bands have recently been photographed with a dispersion of three dense flint prisms. An intensity curve sketched from a Mills spectrogram of a composite band at λ 435 is reproduced in Plate XVII, Fig. 15, and the wave-lengths of the prominent features are given in the following table:

TABLE VI.

Sept. 9 2265 *D*.	Description.	Sept. 9 2265 *D*.	Description.
λ 4324	Beginning of bright band	λ43 55.0	Slight minimum or dark line.
26.3	Suspect dark line.	56.2	Slight minimum or dark line.
28	Beginning of brighter part of band.	57.0	Broad minimum.
28.7	Slight maximum.	59.0	
29.32	Absorption line.	60.03	Narrow maximum.
31.0	Chief maximum of $H\gamma$ band.	60.49	Double dark line.
32.3	Slightly broadened dark line, or minimum.	60.92	
33.5	Maximum.	63.24	Diffuse dark line.
34.5	Broad minimum.	63.9	Maximum.
36.2		64.53	Dark line.
40.49	Narrow dark line.	65.0	Suspect dark line.
41.8	Dark line, broader than preceding.	65.4	Maximum.
41.98		65.8	Double dark line.
42.2		66.3	
43.3	Dark line, broad and diffuse.	66.6	Maximum.
44.5	Dark line, broad and diffuse.	67.4	Dark line (possibly double, separated by about the same amount as preceding).
47.2	Beginning of brightening, due to λ 4363 band.	68.9	Broad and inconspicuous maximum.
48.5	Maximum.	70.2	Diffuse minimum.
49.3	Minimum.	72.45	Narrow dark line.
50.5	Maximum.	74	Faint minimum.
51.4	Diffuse minimum.	77	
52.3	Maximum.	4382	End of band.
53.1	Faint minimum.		
54.2	Principal maximum of band.		

The bands at λλ 3968, 3441, 4363, 4724, 4861, 4959, 5007, and 5752 have been photographed under high dispersion. They all appear to have the same general features, as follows: A pronounced maximum is near the violet edge of the band, flanked on either side by a subordinate maximum. To the red of this group is a broad minimum, or absorption line, while still farther to the red is a group of maxima and minima giving the appearance of four absorption lines. With low dispersion this group was observed in most of the bands as a broad and diffuse absorption line (see Table V, column 5). Further than to note these general characteristics, the spectrograms referred to have not been studied.

The bearing of the foregoing observations upon the various theories of new stars is reserved for a future paper.

It is greatly to be regretted that the delicate details of the original negatives are so largely lost in the reproductions.

Acknowledgments are due to Dr. H. M. Reese for assistance in taking many of the photographs and in reducing some of the measures.

W. W. CAMPBELL,
W. H. WRIGHT.

SEPTEMBER 12, 1901.

NOTE ON THE SPECTRUM OF *NOVA PERSEI.*

At the request of the Director, and with the assistance of Fellow R. H. Curtiss, I secured several spectrograms of *Nova Persei* with the Crossley reflector during September. The spectrograph used was the small one designed by the late Director Keeler. It has been modified by Fellow H. K. Palmer to receive a prism and lenses of quartz, and has been extensively used by him.

On the plates taken are the nine bands observed between λ 387 and λ 501 by Messrs. Campbell and Wright. In addition to these are two bright bands far up in the ultra-violet. The provisional wave-lengths of these new bands are λ 346 and λ 339. The one at λ 346 is very bright, being surpassed on these plates only by the band at λ 387. It is brighter than the band at λ 397, even though the latter is in a region of greater sensitiveness for ordinary dry plates, and the light of the latter is not so strongly absorbed by the Earth's atmosphere.

The new band at λ 339 is fainter than the integrated bands near λ 471, but stronger than the band at λ 464.

The band at λ 346 coincides in position with a line which Mr. Palmer has discovered in some of the well-known nebulæ during the past summer. This strengthens the conclusion that the spectrum of the *Nova* is nebular. It is probable that the band at λ 339 corresponds to an undiscovered nebular line.

After these results were secured, Professor Max Wolf's article in the *Astronomische Nachrichten*, No. 3736, arrived at Mt. Hamilton. His observations demonstrate, without need of further proof, that the recently reported halo around the *Nova* is purely of instrumental

PLATE XVIII.

FIG. 1.—PHOTOGRAPH MADE WITH TWO-FOOT REFLECTOR.
Exposure $3^h\ 50^m$.

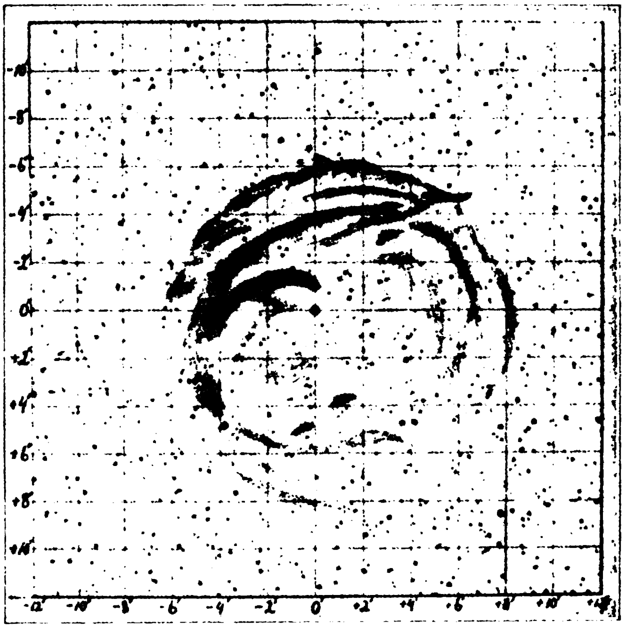

FIG. 2.—DIAGRAM FROM ORIGINAL NEGATIVE.

NEBULOSITY AROUND *NOVA PERSEI*, Sept. 20, 1901.

By G. W. RITCHEY, Yerkes Observatory.

PLATE XIX.

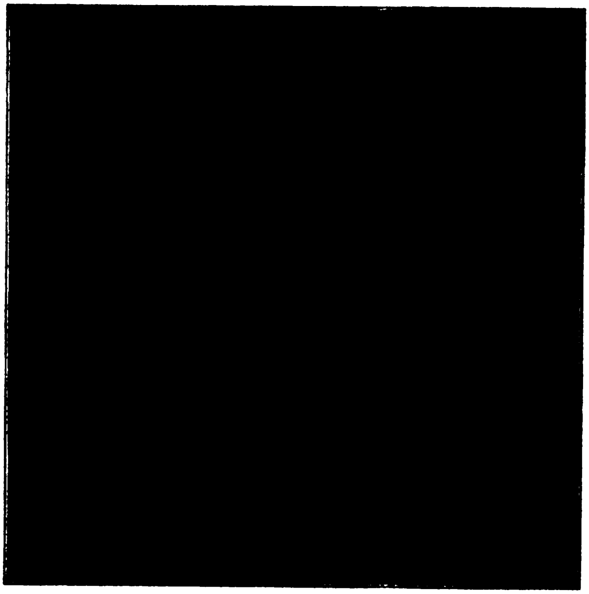

FIG. 1.—PHOTOGRAPH MADE WITH TWO-FOOT REFLECTOR.
Exposure 7^h.

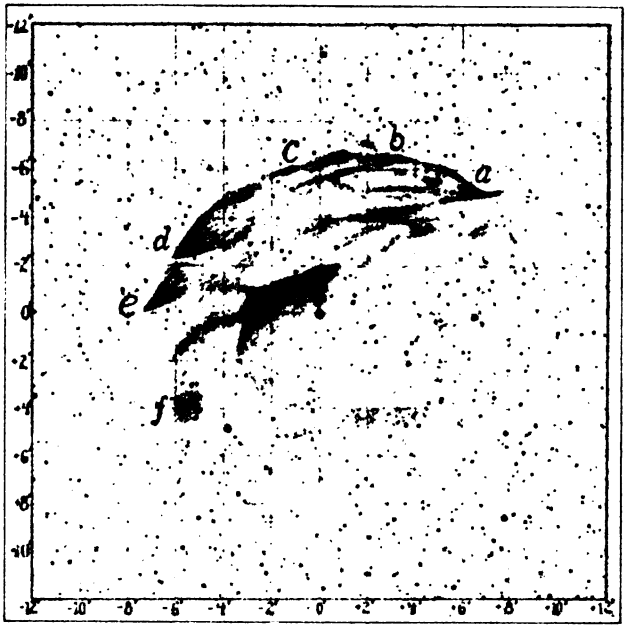

FIG. 2.—DIAGRAM FROM ORIGINAL NEGATIVE.

NEBULOSITY AROUND *NOVA PERSEI*, Nov. 13, 1901.
By G. W. RITCHEY, Yerkes Observatory.

origin. It is undoubtedly true that the chromatic aberration effect, thus observed by Professor Wolf, is due to the ultra-violet bands described above, and especially to the band at λ 346. Professor Wolf's objectives seem to be very transparent, as is shown by the fact that these radiations were able to pass through them at all. His objective *b* evidently transmits them more freely than does objective *a*. If the halo were due to the band at D_3 it should be of practically the same intensity with both objectives.

JOEL STEBBINS.

SEPTEMBER 23, 1901.

CHANGES IN THE NEBULOSITY ABOUT *NOVA PERSEI.*

ON the evening of November 9, 1901, a second photograph of the nebula about *Nova Persei* was secured with the two-foot reflector, but the exposure was cut off by clouds after 90 minutes' exposure had been secured. This negative was immediately developed and examined, and although very weak, the principal condensations of nebulosity were sufficiently strong to show, at the first glance, without the aid of a magnifying glass, that a large change had taken place in the shape of the nebula. The negative was then intensified, and much faint structure was brought out which had been invisible before. It was now certain that the entire southern half of the nebula had been expanding rapidly and nearly radially. On November 11 a telegram was received from Professor Pickering, announcing Perrine's independent discovery of motion in the nebula.

On November 13 a strong negative with seven hours' exposure was secured. The conclusions drawn from the negative of November 9 were all confirmed. Incidentally it was shown that intensification of a weak negative is entirely safe and legitimate; for the details shown on the intensified negative of one and and-half hours exposure agree perfectly, so far as they are shown at all, with those in the negative of seven hours exposure.

Eightfold enlargements of the negatives of September 20 and November 13 were now prepared (in triplicate to make certain that no false details were introduced), and preliminary measurements of the positions of the six principal condensations of the nebula, on each of the two negatives, were made, with a scale and protractor, by means of these enlargements.

The results are as follows: *a* is the principal condensation of the ring, and *b*, *c*, *d*, etc., follow in order of position angle. The negatives of September 20, November 9, and November 13 are designated Neg. 1, Neg. 2, Neg. 3, respectively.

	DISTANCE FROM NOVA.			POS. ANGLE WITH REFERENCE TO NOVA.		
	Neg. 1.	Neg. 3.	Difference.	Neg. 1.	Neg. 3.	Difference.
Condensation *a*..	430″	497″	+67″	133°	129°	− 4°
" *b*..	374	420	+46	167	155	− 8
" *c*..	346	381	+35	202	192	−10
" *d*..	350	395	+45	244	247	+ 3
" *e*..	371	427	+56	263	266	+ 3
" *f*..	366	378	+12	308	304	− 4

In the case of the condensations *a*, *b*, *c*, and *f*, the centers of the condensations were used for the measures, but in the two wing-shaped condensations *d* and *e* it was impossible to decide upon any definite center; consequently the well-defined apex or outer extremity was used in the case of each of these condensations. This may perhaps account for the fact that the change of position angle of these two condensations is positive, instead of negative, as in the others. Photographic copies, and also drawings, of the negatives of September 20 and November 13 are shown in Plates XVIII and XIX.

A comparison of the intensities of the condensations on negatives 1 and 3 shows that the outer parts of the nebula are rapidly fading. On the other hand, the tongue of nebulosity, apparently issuing from the south side of the *Nova*, and curving immediately to the west, is stronger on negative 2, exposed for one and one-half hours, than on negative 1, exposed for nearly four hours; on negatives 2 and 3 this tongue is by far the strongest part of the nebula. This great change of intensity renders it a difficult matter to arrive at a definite conclusion in regard to any change of shape or position of this tongue. Such changes will be carefully watched for in the future; this tongue is so strong that it can be photographed well with the two-foot reflector with an exposure of one and one-half or two hours.

G. W. RITCHEY.

YERKES OBSERVATORY,
November 15, 1901.

ERRATA.

IN Professor Barnard's article, ASTROPHYSICAL JOURNAL, Vol. XIV, No. 3, October, 1901, page 153, line 19, *for* a bright spot *read* a black spot.

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The scope of the ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory. The subjects to which special attention will be given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric, and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects

In the department of *Minor Contributions and Notes* subjects may be discussed which belong to other closely related fields of investigation.

Articles written in any language will be accepted for publication, but unless a wish to the contrary is expressed by the author, they will be translated into English. Tables of wave-lengths will be printed with the short wave-lengths at the top, and maps of spectra with the red end on the right, unless the author requests that the reverse procedure be followed. If a request is sent *with the manuscript* one hundred reprint copies of each paper, bound in covers, will be furnished free of charge to the author. Additional copies may be obtained at cost price. No reprints can be sent unless a request for them is received before the JOURNAL goes to press.

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PLATE XV

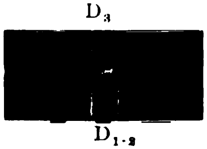


FIG. 7

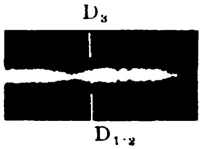


FIG. 8

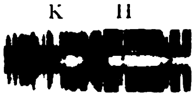


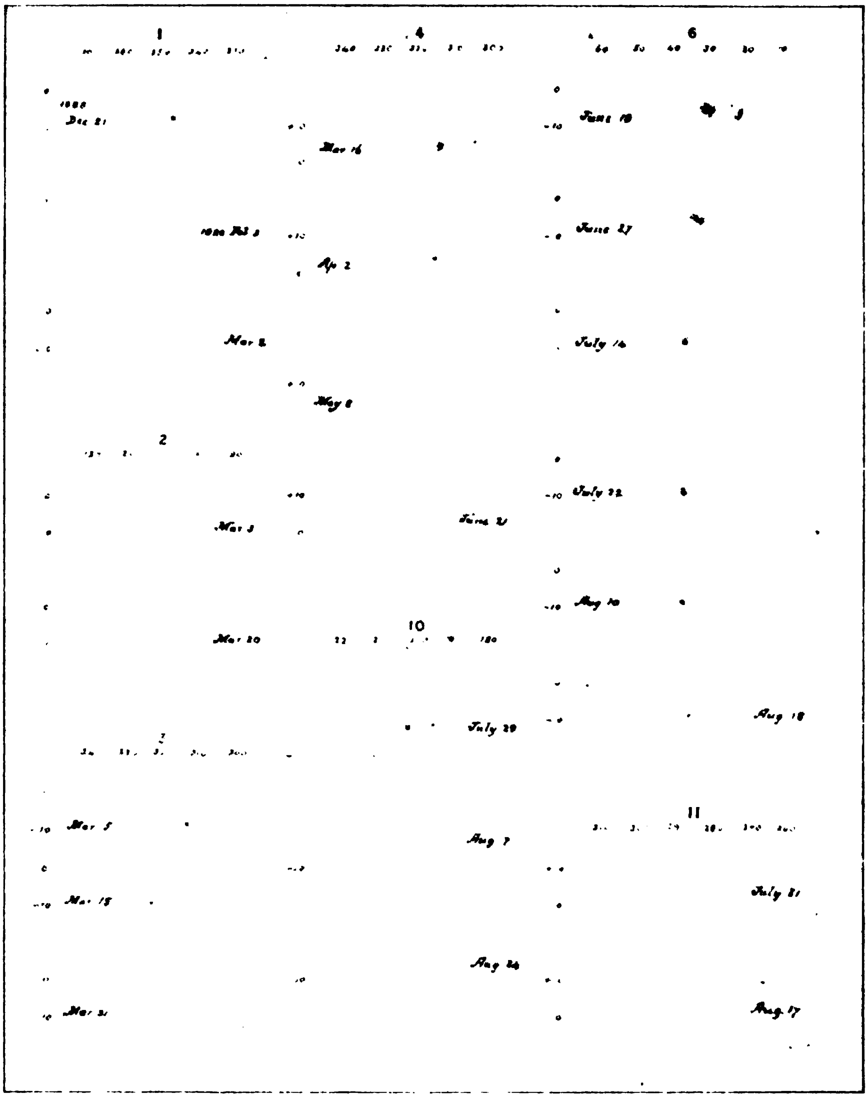
FIG. 9

Fig. 7. — *Nova Persei*, D region, enlarged 8-fold. 1901, February 28.

Fig. 8. — *Nova Persei*, D region, enlarged 8-fold. 1901, March 3.

Fig. 9. — *Nova Persei*, H and K region, enlarged 9-fold. 1901, February 25.

PLATE XX.



Drift of Faculæ in Longitude.

THE
ASTROPHYSICAL JOURNAL
AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

VOLUME XIV DECEMBER, 1901 NUMBER 5

A RUDE ATTEMPT TO DETERMINE THE TOTAL LIGHT OF ALL THE STARS.

By SIMON NEWCOMB

THE total amount of light received from all the stars may serve as a control on theories of the structure of the universe, because the amount of light resulting from any theory should agree with the observed amount. It is also a quantity which we must regard as remaining constant from age to age. It seems possible to determine, not only its integral value for the whole sky, but its value separately in each region of the sky. For these reasons it must be considered as among the most important fundamental constants of astrophysics.

A determination, worthy of at least provisional acceptance, offers no difficulty. Making abstraction of such unknown possibilities as the absorption of light in space, or the existence of unknown luminous bodies in the sky, other than stars too small to be separately visible, the total light of all the stars will be simply the total light of the sky, due allowance being made for absorption and reflection in the atmosphere. Such being the case, it would be quite surprising if no attempt to measure the total amount of light received from various regions of the sky had ever been made; yet I cannot learn of any such determination. This alone can be my apology for publishing so crude a work as the following, which was made only with such apparatus as could readily be got together in a mountain or country resort. Some appliances were kindly supplied by Professor Pickering. I make it known with the hope that it may prove useful in suggesting improved determinations with better appliances, by others.

The problem may be divided into two parts. First, we have the question of the relative brightness of different portions of the sky. This may be expressed by numbers proportional to the brightness of each separate region. We have next the determination, in terms of starlight, of a unit of surface in one or more of these regions. This determination furnishes the unit of measure for the absolute amount of star light received from each unit of the surface, and hence from the whole heavens.

The unit of light which leads to the simplest formulæ for this purpose is that of a star of magnitude 0. As the light received from a square degree of the sky is much smaller than this unit, it will be convenient to introduce a unit one one-hundredth the value of the first. This will be the light of a star of magnitude 5.0.

Either optical or photographic methods may be employed; both are, of course, desirable. As others have much better facilities for making a photographic determination, I have attempted only the optical one.

My original plan was to rest the determination on the minimum amount of light which could be seen by direct vision. I find in the case of my own eye that this is a fairly well defined quantity, being represented by a star of the magnitude 3.8. But the first attempt showed the fovea of my eye to be so insensible to minute lights that no small portion of the sky was visible by direct vision. This plan had therefore to be abandoned and indirect vision used.

The first attempt was made by the sliding tubes of a small spy glass, which could be extended to lengths varying between

30 and 70 centimeters. The ends of the tube were covered with caps having in them openings from 5 to 8 millimeters in diameter. The details of observations with such rough and ready means need scarcely be given. I shall merely state results.

The result of the first attempt was that the minimum portion of sky certainly visible is a circle:

In general average of the region of the galaxy - -	12′ in diameter
In the rest of the sky - - - - - - -	18 in diameter

More careful series of determinations were made by pointing the instrument alternately on the galactic region and in the portion of the sky distant from the galaxy, a certain uniform distance from the galaxy, about 60 degrees, I think, being, in each case, aimed at. The result was:

In the galactic region, diameter - - -	=16′
Distance from galaxy, diameter - -	=18

The determination was then repeated, when vision was had through a dark glass, transmitting 0.5 of the incident light. The patch was taken to look a little fainter. The results were then:

The brighter galactic masses, diameter - -	= 14′
The galaxy in general, diameter - - -	= 20
Near galactic poles, diameter - - - -	= 27

Very surprising is the smallness of the difference indicated between the brightness of the galaxy and that of the rest of the sky. The observations were made in as clear and pure air as I have ever seen, and the contrast between the brightness of the galaxy and the seeming darkness of the rest of the sky was very marked. It is to be remembered, also, that the degrees of brightness as observed may differ from each other in a smaller proportion than the surfaces, because the fainter the illumination is, and the larger the surface over which the light is spread, the greater amount of light required to be distinctly visible.

The second method was to make the comparisons by means of small mirrors which could be set up side by side, so as to reflect different regions of the sky. The results of this method were still more surprising. I was unable to detect any difference in the brightness of the sky within the circle of about 25 degrees galactic latitude. No attempt was made to determine the specific brightness of different portions of the galaxy by means of the mirrors, but one of them was placed so as to give a view of the galaxy in general. The general result was that the illumination of the galaxy was only about twice that of the rest of the sky. I venture to give my notes of the first attempt of this kind, as follows:

Two dark glasses were used: I transmitting about two thirds of the light and II one half of it.

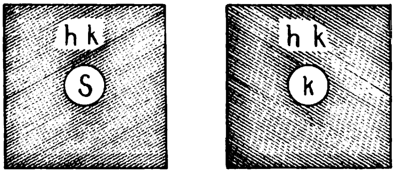
1901, August 16; used mirrors for the first time.
Region A, R. A. $= 15^{\mathrm{h}}.5$. Dec. $= 55^{\circ}$.
Region B, near *Lyra*, just west of it.

(1) Without dark glasses, B sensibly brighter than A.
(2) With B seen through glass I - - - B = A.
(3) With B seen through glass II - B less than A.
(4) Galactic region, when seen through glass II, = A.

On subsequent evenings the attempt was repeated under better conditions, with the result already cited, that no difference was perceptible in the illumination beyond about 25 degrees from the galaxy.

I now pass to the second part of the problem, which is the determination of sky light in terms of star magnitude. As it is impossible to concentrate the light of a surface into a small space, we must, in order to compare light of star and sky, spread that of the star out by means of a lens; a concave lens is the best for this purpose. In doing this we meet with the difficulty that the expanded light of the star is superposed upon that of the sky around it. A device was therefore adopted of cutting down the brightness of the expanded image by an absorbing glass to that of the sky. In doing this, however, the eye is likely to be deceived by contrasts. It need hardly be said that only one eye must be used in such comparisons. To avoid error from this source the system finally adopted was this:

By means of a concave lens the light of a star is spread out into an image of known angular diameter D. This image is then reduced by being viewed through a dark glass, transmitting the fraction *h* of the light. Thus we have in the field of vision a diffused image *S* of the star and of the sky around it, the whole enfeebled by the fraction *h*. Alongside of this arrangement let there be a second, consisting of the same or an equally dark glass, having in it an opening of which the apparent angular diameter shall be the same as that of the diffused image of the star. We thus have in the field of view two similar images as shown in the following scheme: *K* is the sky itself; *hK* the sky seen through the dark glass, *S* the diffused image of the star reduced by the fraction *h*. A star is to be taken, such that the two images shall appear equal.



In the observations made on this system the dark glass was that of a pair of spectacles which, from the best determination I was able to make, transmitted 0.16 of the incident light.

Two concave spectacle lenses were used, one of 6, the other of 8 dioptrics strength. That is, the effective focal distances were one-sixth and one-eighth of a meter.

The following are the notes of the most satisfactory observations I was able to make:

1901, September 16, at home of A. Graham Bell, near Baddeck, Cape Breton Island. Night very fine. Observations commenced at $8^{\rm h}$ $15^{\rm m}$, after the setting of the Moon.

LENS OF SIX DIOPTRICS.

α *Pegasi*, reduced to 0.16 = sky near it.

γ *Draconis*, reduced to 0.16, fainter than sky near it.

α *Aquilae*, > Milky Way near it.

α *Ophiuchi* = sky 20 degrees west of it.

α *Cygni*, slightly fainter than general average of the brighter portions of the Milky Way between *Cygnus* and *Aquila*.

γ *Pegasi* < sky southwest of it.

The star of which the brightness seems to correspond most exactly to that of the sky at galactic latitude 40 degrees is α *Pegasi*.

LENS OF EIGHT DIOPTRICS.

α *Cygni* < brightest portion of Milky Way.
α *Aquilae* > brightest portion of Milky Way.
α *Aquilae* = bright agglomerations 20 degrees south.
α *Pegasi* < surrounding sky.

This lens does not work satisfactorily except on stars brighter than magnitude 2.

LENS OF SIX DIOPTRICS AGAIN.

α *Andromedae* slightly < sky south of it.
α *Cygni* = brightest part of Milky Way.
α *Lyrae* much > any part of Milky Way.

Before deriving the results from these observations I shall describe a third class, comprising direct comparisons of the diffused images of stars or groups of stars, superposed on the background of the sky, with the agglomerations of the Milky Way. No dark glass is used in these observations.

At the Moosilauke, 1901, August 16. Concave lens of 2+4 = 6 dioptrics. Looked through both combined.

γ *Lyrae*, + β near maximum, expanded, = mean of neighboring galactic masses seen through the same lens.

Star of magnitude 3.0 = brighter galactic agglomerations near *Aquila.*

Diffused constellation *Delphinus* = average of galactic agglomerations near it.

BADDECK, SEPTEMBER 16. LENS OF EIGHT DIOPTRICS.

β + γ *Lyrae* < average of Milky Way.
γ *Cygni* > brightest agglomerations south of it.
Delphinus as a whole = brightest portions of galaxy.
α *Cygni* much > any part of galaxy.
α + β *Lyrae* = faintest of galactic masses.

I now proceed with the derivation of results from these observations, beginning with those in which an absorbing medium is used to compare the light of that star with that of the sky. In this the diameter of the pupil is to be considered, since the absolute brightness of any object observed with a pencil of rays filling the whole diameter of the pupil varies as the square of that diameter. I have found the effective diameter of the pupil of my eye, that is, the diameter of the external pencil of parallel rays which, after refraction by the cornea, will fill the pupil, to be about 5 millimeters.

Such being the case, and assuming the eye to be accommodated for parallel rays, the image of a star seen through a concave lens of p dioptrics virtual focus in contact with the cornea will be expanded into an image of diameter

$$\frac{57^\circ.2p}{200} = 0^\circ.286p.$$

The most convenient unit of sky surface for our purpose is the area of a circle 1 degree in diameter. Taking as the measure of brightness the amount of light falling on this unit of surface, it follows that if S be the amount of light emitted by a star, the brightness of its expanded image will be

$$b = \frac{S}{(0.286p)^2} .$$

If, instead of being in contact with the cornea, the lens of focal distance $-f$ is at a distance d from it, the angular diameter of the diffused image will be diminished in the ratio $f : f + d$. But the angle which the diameter of the pupil subtends, as seen from the virtual focus, is diminished in the same proportion, as is also the square root of the amount of light which the pupil receives from the star. Hence

The brightness of the diffused image of a star seen through a concave lens by a normal eye is independent of the distance of the lens from the eye.

If the eye is not normal the combination is in effect equivalent to the use with a normal eye of two lenses, one the negative of the lens which, in contact with the cornea, would correct the abnormal refraction; the other the actual lens used.

In the present case the eye has a mean abnormal refraction of about $+0.5$; it will serve our present purpose if we allow for this by diminishing the negative power of the lenses by this amount, thus assigning to p the values 5.5 and 7.5 for the two lenses. We thus have, for the brightness of star images seen through the lenses:

$$\text{Lens of } 6D\text{: } b = \frac{S}{2.47} .$$

$$\text{Lens of } 8D\text{: } b = \frac{S}{4.60} .$$

When a star is viewed in the way in question its light is superposed upon that of the sky around it. Let us put

$y =$ brightness of sky around the star.

The brightness of the image will then be increased by y. This image being viewed through an absorbing-glass of power h, the brightness of the image as seen will be

$$b = h\left(\frac{S}{2.47} + y\right) \text{ or } h\left(\frac{S}{4.60} + y\right).$$

Putting, as already stated, $h = 0.16$, we have for the brightness of the images

$$b = 0.065S + 0.16y \quad . \; . \; . \quad (6D)$$
$$\text{or} \quad b = 0.035S + 0.16y \quad . \; . \; . \quad (8D).$$

To obtain the results these expressions are to be equated to y itself, stars having been taken to nearly satisfy this equation.

As I was not able to detect any well-marked difference of brightness between different portions of the non-galactic sky, I shall use but one value of y. Taking the light of a fifth magnitude star as unity we have, for a star of magnitude m

$$S = 10^{2.0 - 0.4m}$$
$$\text{or} \quad \log S = 2.0 - 0.4m.$$

Taking the magnitudes of the stars from the Harvard photometry we have the following equations from the observations :

LENS OF SIX DIOPTRICS.

α *Pegasi*,	$m = 2.5$	$0.65 + 0.16y = y$.
γ *Draconis*,	$m = 2.5$	$0.65 + 0.16y < y$.
α *Ophiuchi*,	$m = 2.2$	$0.86 + 0.16y = y$.
γ *Pegasi*,	$m = 3.0$	$0.41 + 0.16y < y$.
α *Andromedae*,	$m = 2.1$	$0.94 + 0.16y < y$.

The best result we can get from these rather discordant equations is $y = 0.90$.

That is to say, a circle of the non-galactic sky 1 degree in diameter gives 0.90 of the light of a star of magnitude 5.0.

A more precise determination of the brightness of the galactic agglomerations is obtained by the third method. But when a single star is used the eye is liable to underestimate the brightness, by substituting for it a certain fraction of the total amount of light, that is to say, if n be a considerable number, say 20 ±, a light of $20s$ spread over an area of $20a$ will be estimated as brighter than one of s spread over the area a. I first noticed this at Baddeck.

I cannot identify the star of supposed magnitude 3 which, expanded into an area of about 2.5 degrees, looked equal to the galaxy, and regard the result as too great, for the reason just stated. For the galaxy let us put

g_2, brightness of mean agglomerations,
g_3, brightness of brighter agglomerations,

these values expressing amounts of light in addition to those received from the background of the sky.

The combined light of β and γ *Lyrae* I consider to have been diffused over an area, subjectively considered, of 7 degrees, the whole being expanded into an ill-defined, diffused mass, instead of a pair of circular disks, which would have been the actual form. For the two stars we have $S = 9.6$, and therefore $g_2 = 1.4$.

The most definite result seems to be that given by the constellation *Delphinus*, which, with the lens of eight dioptrics, was expanded into a mass of brightness g_3. The area as it appeared may be estimated at 14 circular degrees. The total light of all its most condensed collection of lucid stars is 13. It would follow from the observation of *Delphinus* that the brightest regions of the galaxy are 0.93 brighter than the background of the sky in *Delphinus*. This background seemed to me but little in excess of that of the non-galactic sky. Calling its brightness y', we should have $g_3 = 0.93 + y' - y$.

Assuming the background to be 50 per cent brighter than that of the non-galactic sky we have, from $y = 0.90, g_3 = 1.38$.

That is to say:

The total mean brightness of the brighter agglomerations of the Milky Way, including the light of the sky, is 2.28. Subtracting 0.90 for the light of the non-galactic sky, we find that the total light per unit of surface received from these agglomerations is 1.38, or about 50 per cent. more than that from an equal area of the non-galactic sky.

Let us compare this conclusion with that from observations of the first class, in which the visibility of the sky through a small opening was examined. There is one uncertain element in the interpretation of the latter, the effect of the size of a surface on its visibility under a faint illumination. If we have a definite quantity of light it will be more and more distinctly visible as it is more condensed. In other words, if we suppose a series of illuminated circular disks subtending various angles, the amount of light necessary to make one of them visible will be greater, the greater the surface. But this amount will not increase in proportion to the surface because the visibility of every portion is reënforced by the illumination of the surrounding portions. I am not aware that any determination has ever been made of the law governing this case. Our result, therefore, must be in part hypothetical. The most definite result seems to be that the minimum portion of the sky distinctly visible near the pole of the galaxy has about double the diameter of the least visible portion in the brighter galactic agglomerations. The former has, therefore, four times the surface of the latter. If the absolute amount of light is the same we should conclude from this that the agglomerations were four times as bright as the background of the sky near the galactic pole, so that

$$g_3 = 3y.$$

All we can say of this result is that it is too large, but, apart from its considerable probable error, not much too great. If, as the mean result, we suppose the amount of light required to be visible to vary inversely as the diameter we should have

$$g_3 = y$$

a result in agreement with that derived from the observations of the third class.

One conclusion from these observations may seem to require explanation. From the value of y already found the amount of light received from a patch of non-galactic sky 12′ in diameter is 0.036 of that of a star of the fifth magnitude, which is somewhat less than the light of a star of the eighth magnitude. The conclusion that a star of the eighth magnitude is not below the limit of visibility on a dark ground requires verification, but may be accepted on the ground that the ordinary invisibility of stars below the sixth magnitude arises from the light of the sky on which the star is projected. The latter fact may be easily verified by looking at the sky through a pair of dark-glass spectacles. With those already mentioned, which reduce the brightness of a star by about two magnitudes, I noticed that, although my eye is now far from being of the best, 51 H *Cephei* was faintly visible, while δ *Ursae Minoris* was very distinct. The magnitudes of these stars being 5.2 and 4.2 it seems that, against the background of the sky reduced to one-sixth of its normal brightness, a star of 7.2m is visible to my eye.

Allowing as wide a range of uncertainty as I think we should attribute to these observations, the general conclusions may be summed up as follows:

Taking as the unit of surface that of a circle 1 degree in diameter, and measuring its brightness by the amount of light received from it, in terms of the light of a star of magnitude 5.0, as unity, the brightness of the sky near the galactic pole is 0.9 with a mean error ± 0.2.

In the brighter agglomerations of the galaxy, measuring the brightness in each case by its mean value in a circle not less than 5 degrees in diameter, its brightness is equal to that near the galactic pole, plus a quantity which probably lies between 1.0 and 1.5.

These results are at variance with those which I had supposed to be derivable from existing photometric and statistical data. We suppose the light of the background of the sky to be due wholly to the telescopic stars; and the fact is that the amount of light which results from these observations is no greater, but perhaps less than we should expect from the totality of such stars. Now, it is well known that the thickness of the stars to magnitude 9.0 steadily increases from the galactic pole toward the galaxy itself. According to Seeliger's count the number of these stars at 30 degrees galactic latitude is nearly double that at the galactic pole. Moreover, the condensation continually increases as we include fainter stars. From the ordinary ratio of the number of stars of each magnitude to that of the stars one magnitude fainter, it is readily shown that the total amount of light received from the stars of each successive order of magnitude should continually increase as we include fainter stars. The gauges of Herschel show ten and even twenty times as many stars per square degree in the galactic agglomerations as near the galactic pole. We should therefore suppose that the sky at 30 degrees galactic latitude ought to be more than twice as bright, and in the agglomerations, ten times as bright as at the pole. Moreover, the impression one gets by simply looking at the galaxy is certainly that of being several times brighter than the background of the sky.

One explanation of the paradoxical character of my result will at once present itself for consideration. Of the light which reaches us from a heavenly body, not only is a portion lost by the absorption of our atmosphere, but a certain fraction is also reflected from the air. It follows therefore that the light received from any region of the sky is composed of two parts, the one reaching us directly from the telescopic stars, the other reflected from all the stars above the horizon. I do not know whether any accurate determination of the proportion of light thus reflected has ever been made. I essayed, in a way even more rude than that of the rest of the observations, to determine it at the Moosilauke. The method used was to lay a sheet of white paper on the ground where it was exposed to the full light of a large portion of the sky, and also to that of the direct rays of the Sun. Direct sunlight was cut off from one portion by an opaque obstacle while the other portion was viewed through an absorbing glass. I found that, using the glass already described of absorption 0.84, the portion of the paper illuminated by the Sun, when seen through this glass, generally looked brighter than that illuminated only by skylight, but did not seem twice as bright. The principal difficulty in making a satisfactory estimate arises from the blue color of the light of the sky, which I found it difficult to compare with the comparatively brown light of the Sun. My general conclusion was that the amount of reflected light was probably one tenth that received from the Sun, perhaps a little more.

Assuming that one nth of the light coming from a heavenly body is reflected by the atmosphere, the total amount of light received from any small region of the sky is that coming from the telescopic stars in that region, diminished by atmospheric absorption and reflection, and increased by one nth of the amount of light we should receive from that region, were the stars equally scattered over the heavens. Putting $n = 10$, the effect would be slight, and altogether, it does not seem that any admissible use of these numbers would lead to a material modification of my results.

The question will naturally arise whether, possibly, the sky may not have been illuminated by extraneous light during my observations. In my opinion there was no appreciable amount of light from any terrestrial source. At neither station were there electric lights within many miles. The only lights within a radius of five or six miles were a few gas lights in neighboring towns which, I believe, could not have had any observable effect, and some lanterns of which the effect was insignificant.

Care was taken to observe only when the Moon was below the horizon. The planets *Jupiter* and *Saturn* were in the sky, but it is clear that their light could not have affected the result.

On the whole it seems either that my observations are wholly at fault—erroneous by an amount which I should find it difficult to account for, or we must materially modify our conclusions from the combination of star gauges with the existing photometric estimates of star light. One step in this latter direction I have made in a recent number of the *Astronomical Journal.* On discussing the magnitudes of the Cordoba *Durchmusterung*, when reduced to the Harvard photometric standard, I reach the surprising conclusion that, from the data there presented, there was no increase in the total amount of light received from all the stars of each order of magnitude, as had always been inferred from previous counts. If a similar conclusion is drawn from the study of statistics pertaining to the northern heavens the way for a reconciliation may be open. Considering only the present rude observations, their result is about this:

The total light of all the stars is about equal to that of 600 stars of magnitude 0, with a probable error of one fourth its whole amount. There is, however, more room for a positive than for a negative correction; it is not at all unlikely that the number may be greater than 800.

The large range of uncertainty will seem less striking if we reflect that it only amounts to ± 0.3m or ±0.4m where expressed in star-magnitude.

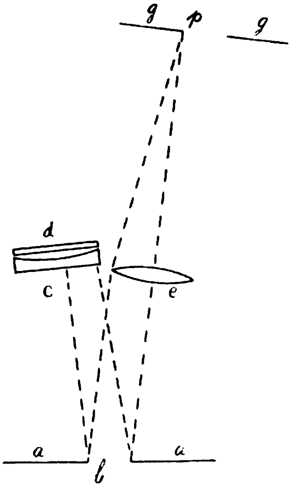
I regard the present paper useful mainly in suggesting a careful investigation by others with better instrumental means than the rude ones at my disposal. The determinations should be made by photography as well as optical; indeed, were it not that the photographic plate measures mainly the blue light, the optical method would be scarcely worth employing. As a matter of fact, however, it affords a nearer approximation to the total energy than does the photographic effect. I therefore make the following suggestions as to the method of conducting the experiments.

The brightness of various portions of the sky may be determined not only by their juxtaposition through reflection in mirrors, but by comparing various portions of the sky with a faintly illuminated canopy, care being taken to use a light of the same color as that of the sky. Comparative estimates could, in this way, be made with great precision, but I fear it would not be possible to fix a value of the albedo of the canopy with such precision that the method could be used for absolute measures.

The first method, in which the sky is viewed through a small opening, is subject to a large probable error in the individual observations, but by repeating them, pointing in rotation on different regions of the sky, I think that constant error could be avoided. This seems to be the method which is open to least doubt.

In the adoption of the second method the appliances used should be attached to a telescope with an equatorial mounting, which I was unable readily to command at either station.

The accompanying figure embodies my idea of the best form of apparatus for the purpose. The dimensions which I give are only provisional, serving as a preliminary guide to the observer.



a a is a metallic plate, with a hole *b*, acting as an artificial pupil of constant diameter. I did not use this in my observations. The diameter of *b* should be less than that of the actual pupil, perhaps 4 mm. *c* is a concave lens of focal length −16cm.

d is an absorbing glass in contact with the lens.

e is a convex lens, of which the power may be about the same as that of *c*, taken positively.

g g is a dark glass of the same strength as *d*, having through it an opening *p*, placed in the focus of *c*. A photographic film may be used, if the cutting of a hole in the glass is impracticable, but the hole is to be preferred.

The distance of *g* from *e* should be such that the angular diameter of the hole *p*, as seen by an eye behind *a a*, should be equal to that of the diffused image of a star seen through the hole *b* and the lens *c*.

The entire apparatus should be attached to a bed-plate or rod mounted on axes so as to admit of being rapidly pointed to various parts of the sky. Care must be taken to so adjust the lenses c and e and the plate $g\ p\ g$ that b shall be filled by each pencil of light, especially that g does not cut off any light from the star.

The whole combination should admit of easy reversal on a longitudinal axis, so that the images of the star and of p on the retina may be readily interchanged.

SPECTRAL PHENOMENA CONNECTED WITH THE COOLING OF VERY HOT STARS.

By H. KAYSER.

IN the spectra of several stars, some of the hydrogen lines appear bright and others dark. Campbell[1] has thoroughly investigated this appearance and has found that the brighter lines always correspond to greater wave-lengths, and that the brightness decreases with decreasing wave-lengths while the darkness of the dark lines increases in the same order. Campbell considers that these stars represent the transition between Vogel's Ia class and Ic class. He believes it possible that this transition takes place in such a way that all the bright lines do not become dark at the same time, but that the change occurs by degrees. He cannot, however, give any explanation of this phenomenon.

Scheiner[2] opposes this opinion and writes categorically as follows: "The statement that in any spectrum, bright and dark lines belonging to the same substance can at the same time occur, so contradicts the simplest consequences of Kirchhoff's law that it must be dismissed as impossible." This expression of opinion shows that Scheiner is not acquainted with the numerous experiments which have been made on the reversal of spectral lines, since all these experiments have uniformly shown that only single lines of a spectrum can be reversed, whether it is a question of self-reversal or one of reversal on a continuous background. Also this appearance, far from contradicting Kirchhoff's law, is in reality in most perfect harmony with it, as may easily be seen from an elementary consideration of the law.

If e be the coefficient of emission of a radiating body 1, for a certain wave-length, and E that of a second absorbing body

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[1] W. W. CAMPBELL, ASTROPHYSICAL JOURNAL, 2, 177, 1895.

[2] J. SCHEINER, *Astron. Nachr.*, No. 3733, p. 195, 1901.

2, whose coefficient of absorption is A, then according to Kirchhoff

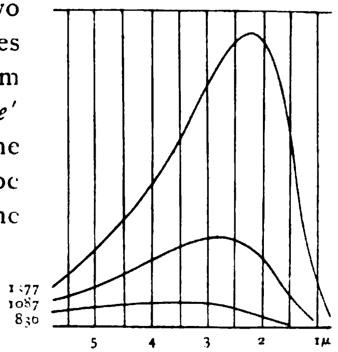
$$E = e'A,$$

where e' represents the coefficient of emission of a perfectly black body at the same temperature as the absorbing body 2. As is well known, the absorbing body 2 must be colder than the body 1 in order to render reversal possible, *i. e.*, $e' < e$. Whilst the body 1 is emitting the amount e, the fraction eA will be absorbed by the body 2, which, however, adds to the total radiation the quantity $E = e'A$, so that from 1 and 2 together we get $e - (e - e')A$.

If a line of a spectrum is visibly reversed then this intensity must obviously be smaller than e; so that the reversal will be more distinct the greater $(e-e')A$ is, as compared with e: that is, the greater the difference of temperature between 1 and 2 and the coefficient of absorption of 2 are. Therefore for a given difference of temperature all the lines will not be reversed, but only those for which $(e-e')A$ is large enough. Those lines for which A, and therefore E, is very small will not become visible as dark lines: that is, in general, only the strongest lines will exhibit reversal.

In order to investigate what becomes of the non-reversed lines we must decide whether the body 1 gives a continuous spectrum or whether it is the same gas as 2. In the first case the bright lines disappear in the scarcely brighter background, as Liveing and Dewar have several times observed. In the second case the lines remain bright, so that the spectrum of the gas is a mixture of bright and dark lines. So much for Scheiner's sweeping assertion. Returning to the original question, the conclusion arrived at above that first of all the brightest lines are reversed, appears to be inconsistent, since the longest wavelengths of the hydrogen spectrum are the brightest, the intensity decreasing from the fundamental to the shorter waves of the series, and accordingly one would expect to find the longer wavelengths reversed and the shorter ones bright. I think, however, that this apparent contradiction can be explained.

In the last few years we have become more intimately acquainted with the emission curves of a perfectly black body. In the accompanying diagram the curves corresponding to temperatures of 836°, 1087° and 1377° as observed by Lummer and Pringsheim are given, and it seems to me they afford a solution to our problem. Suppose the two upper curves to be those for our bodies 1 and 2. We can read off from them for any wave-length the quantity $e-e'$ as the difference of the ordinates at the wave-length in question. It will be seen at once from the form of the curves that the ratio of $e-e'$ to e for long wave-lengths is comparatively small and increases gradually, becoming relatively large when the maximum of the lower curve is passed. Beyond a certain wave-length, the value of e' becomes practically zero, so that the ratio $e-e'$ to e is approximately unity. If therefore A were identical for all spectral lines we should get the result that $e-(e-e')A$ differs more from e and therefore the reversal becomes stronger as we proceed to smaller wave-lengths and that the reversal becomes particularly strong when we pass the wave-length of maximum energy for the absorbing body. But in a series the value of A decreases in the same proportion, thereby weakening the effect of the variation of $e-e'$ without however necessarily annulling it. This would then explain well why the short wave-lengths are most easily reversed.



The phenomenon is, by the way, not confined to stellar spectra, for as early as 1871 Cornu drew attention to the same appearance in arc spectra and anyone who has photographed arc spectra can confirm it.

Should my explanation be correct some interesting results would follow. From the position of that line in the spectrum where the darkness of the reversed lines begins rapidly to increase, some idea of the temperature of the absorbing enclosure could be obtained, the temperature being higher the greater the number of bright lines. I admit that the phenomenon becomes more complicated by Campbell's beautiful observation that the intensity of the hydrogen lines does not necessarily decrease from the first member but may actually increase for the first few members of the series, which seems to me to indicate a very high temperature.

In any case I consider that the existence of bright lines proves that the temperature is very high and the maximum of the c' curve must lie in the visible part of the spectrum. On the other hand, the fact that we have a mixture of dark and bright lines proves that the nucleus does not radiate like a solid body, that is, that its density is very small compared with other stars, which is also an indication of a high temperature.

If then a star, in which the whole hydrogen series is bright, gradually cools down, the series will by degrees become reversed, beginning at the lowest members and last of all *Ha*. Campbell was therefore perfectly correct in his supposition.

The only hypothetical part of this explanation is that we compare the emission from a gas with that of a solid body, *i. e.* we assume the intensities of the lines to be approximately the the same as those which a perfectly black body would have in the same part of the spectrum. I believe that this may be safely assumed in the case of a line series and the above mentioned observations of Campbell's are in favor of it. At any rate, it must be correct for the case of an infinitely thick layer of gas.

BONN, October 1901.

ON DRIFT IN LONGITUDE OF GROUPS OF FACULÆ ON THE SUN'S SURFACE.

By A. L. CORTIE.

FROM a discussion of 108 faculæ on photographs taken in the year 1884, at Potsdam, Wilsing found no indications of any drift in longitude with decrease in latitude, such as was established by Carrington for Sun-spots. Stratonoff, however, in his memoir "Sur le mouvement des facules solaires," determined that in the case of faculæ connected with spots, they followed the same laws of rotation as the spots, although in general the faculæ had a greater velocity of rotation. Moreover, faculæ in different latitudes had different velocities, but the law seemed to be more complicated than in the case of spots. In the discussion of the observations, 234 plates were chosen for the years 1891–1894. On these plates 2245 positions were measured in 1062 separate faculæ. The great majority of them were only observed during one day, 103 were observed for two days, and 5 during three days.

Previously, however, to the appearance of Stratonoff's paper, Father Sidgreaves, in his "Notes on Solar Observations at Stonyhurst College Observatory,"[1] had treated of selected groups of faculæ observed during the year 1889, and which had been followed as entire groups in their transits across the Sun for considerable periods of time. He showed that the faculæ under this aspect followed the same law of drift in longitude as the spots. In his paper only the results of the discussion were given, and the detailed presentment of the observations on which the conclusions were founded was reserved for a future occasion.

The present paper is therefore supplementary to that of Father Sidgreaves, and, while traversing the same ground, gives a more detailed, and at the same time an independent treatment of the observations. Moreover, it is illustrated by diagrams of the several groups of faculæ studied, which serve as a most convincing and striking evidence of the reality of the drift. The question proposed, therefore, is whether groups of faculæ as a whole, and not separate determined points in any one group, give evidence of the same or a similar law of decrease of angular velocity with latitude, as the spot groups do.

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[1] *Monthly Notices R. A. S.*, Vol. LV, No. 1, November 1894.

As was pointed out in the former paper, the first difficulty in treating groups of faculæ is that of identification, and the following of any specified group in its passage across the solar disk, especially as it can be observed only when near the limbs of the Sun. On the Stonyhurst drawings the average distance from the limbs at which faculæ are drawn is half the radius of the solar image. In years of maximum activity, when the faculæ are so numerous that they practically form luminous belts all round the Sun, it is well-nigh impossible to distinguish the different outbursts one from another in all the stages of their life history. The difficulty, however, is not so great in the years of minimum, when the outbursts are less numerous and more separated in time. If, too, those groups of faculæ be selected for study which are connected with spots, the difficulty of identification is considerably diminished. Moreover, the law of the formation and growth of faculæ accompanying spots is a further guide to identification, the various phases in their growth being generally as follows:

First a few intensely bright flecks of faculæ are seen, which after a day or two are followed by the appearance of small spots. In the earlier stages of the life-history of the spots, the faculæ cling closely round the spot-groups, growing with the spots, and being very bright. When, however, the spot-group is nearing extinction, the faculæ attain their fullest development, and appear in their most typical branching forms. The average life of a group of faculæ is from four to five times that of the spot-group which it accompanies. As the faculæ groups grow older they become less compact and bright, and spreading over wider areas gradually disappear.

In the present instance the year of minimum solar activity 1889 was selected for study. Of 121 different groups of faculæ drawn at Stonyhurst during that year, 25 were connected with spots. Of these 25 again, 13 have been closely followed and watched during a prolonged period, ranging from 120 to 19 days. These are set down in the following list :

Number	First observed	Recorded duration in days	Mean Heliographic		Relative magnitude
			Longitude	Latitude	
1	1888 Dec. 11	81	354°	— 9°	2
2	1889 Feb. 21	38	116	— 8	3
3	March 5	27	320	— 8	2
4	March 13	100	319	+ 7	2
5	May 5	110	217	— 3	5
6	May 30	109	33	— 8	7
7	June 23	29	64	— 8	1
8	July 12	35	89	— 8	2
9	July 26	28	339	—26	1
10	July 27	27	203	— 2	1
11	July 29	19	296	+ 5	1
12	July 31	120	152	—24	5
13	Aug. 10	23	84	— 9	2

These thirteen cases were carefully selected after inspection of the seventeen sheets, one to each solar rotation, which cover the period 1888, September 24, to 1890, January 1. On these, both the spots and the faculæ have been set down in their proper positions, the heliographic co-ordinates of each member of every group having been determined from the original drawings by means of a set of very accurate orthographic projections of the parallels of longitude and latitude of the solar disk for every degree slant of its polar axis. A full description and discussion of the accuracy of these projections is given in the *Monthly Notices R. A. S.*, Vol LVII, No. 3, January 1897. This laborious work, as well as the original drawings, is due to Mr. William McKeon.

In the study of the drift of the selected groups, the method of Carrington in his *Observations of the Solar Spots* has been adhered to. The center of each group of faculæ chosen was that which, after due inspection of the diagrams, was judged to give the most truthful result for the diurnal motion. One specimen of the method followed in all cases will suffice:

GROUP 12.

Rotation	At days	Long.	Lat.	Means		
				d.	Long.	Lat.
I.	211.48	155°	—22°	216.99	158°	—22.5°
	213.40	156	—22			
	221.53	161	—23			
II.	240.63	156	—24	244.78	155	—24.0
	248.46	156	—23			
	249.38	152	—25			
III.	267.36	151	—25	271.90	150	—25.5
	276.44	149	—26			
	294.39	148	—25	294.94	145	—25.5
	295.49	142	—26			

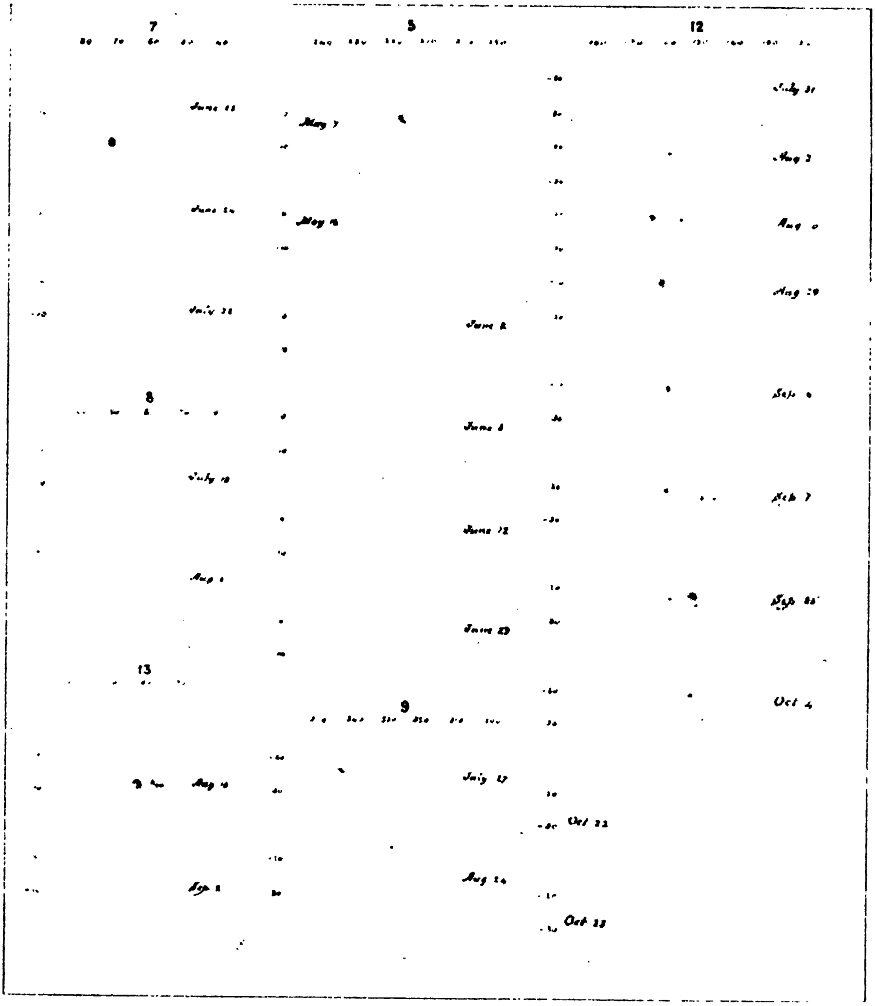
Hence

At days	Long.	Lat.	Diurnal motions
216.99	158°	—22.5°	— 7′ and +3′
244.78	155	—24.0	—11 and +3
271.90	150	—25.5	—13 and 0
294.94	145	—25.5	

mean diurnal motion —10′ and +2′ for latitude —24°.

The results for all the groups similarly studied are collected in the following table. The signs prefixed to the concluded diurnal motions are such that + in longitude indicates rotation faster than 14° 11′ for each solar day, Carrington's adopted mean, and + in latitude, motion towards either pole. As in Carrington's results for the spot-groups, the figures are given to the nearest whole number.

PLATE XXI.



Drift of Faculæ in Longitude.

Number	Mean latitude	Mean Diurnal Motion	
		Longitude	Latitude
1	— 9	+ 8′	+1′
2	— 8	+21	+0
3	— 8	+38	+2
4	+ 7	+15	+0
5	— 3	+11	+2
6	— 8	+14	+5
7	— 9	+ 6	—2
8	— 8	+31	+7
9	—26	—15	+2
10	— 2	+19	+2
11	+ 5	+ 7	+0
12	—24	— 10	+2
13	— 9	+18	+4

Collecting these results for the different latitudes, and comparing them with Carrington's results for spots, we have:

Latitude	Number of groups	Mean Daily Angular Motion	
		Faculæ groups (Stonyhurst)	Spots approximate (Carrington)
+ 7°	1	14°.5	14°.3
+ 5	1	14.3	14.7
— 2	1	14.5	13.9
— 3	1	14.4	14.2
— 8	4	14.8	14.3
— 9	3	14.4	14.4
—24	1	14.0	13.8
—26	1	13.9	13.7

The rotation period 14°.2 per solar day for the spots applies to the latitude 14° north and south in Carrington's final results. For higher latitudes the rotation period is slower and for lower latitudes faster. The above table shows that at least in the cases studied the faculæ too follow the same law of drift, and corroborates for groups followed during long periods of time in their entirety, what Stratonoff has established for separate points of faculæ followed at most for three days.

An inspection too of the accompanying diagrams in which these carefully selected cases are set down in their true positions, all doubtful cases having been rigidly excluded, shows the drift established by the tables in a most satisfactory manner. In some cases an apparent lagging of the faculæ behind the spot will be noticed. This, however, is due to the disappearance of the following members of the spot-groups. The faculæ have remained in the positions they occupied relatively to the vanished members of the spot-groups. Seeing that the faculæ live so much longer than the spots, and, after the disappearance of the spots, are not disturbed by the action of spot formation, were the difficulty of identification overcome it would seem possible to establish a more uniform law of drift from observations of them, than even from the spots. The table also seems to show, in the limited number of cases discussed, a faster rate of daily angular motion for the faculæ than for the spots.

STONYHURST COLLEGE OBSERVATORY,
July 22, 1901.

SOME NEW PECULIARITIES IN THE STRUCTURE OF THE CYANOGEN BANDS.

By A. S. King.

In this paper a short account is given of the writer's investigation of the arc spectrum of carbon, special notice being taken of a banded structure in the ultra-violet region, which appears to have been overlooked by previous observers; at least these bands have not been measured and considered in relation to the other bands of the carbon spectrum.

Photographs of the spectrum were taken by means of a Rowland concave grating of fifteen feet radius, ruled with 15,000 lines to the inch. The well-known bands in the violet and ultra-violet with heads at 3883 and 3590 affect the photographic plate so strongly that an exposure of about ten seconds is sufficient for good definition of these bands. It is only on plates which have been exposed for a much longer time (at least one minute), so long that the bands just referred to are much over-exposed, that we can see another series above the 3590 band. This series begins at 3465 and reaches almost to the copper line at 3274. It consists of eight dense portions which have the appearance of heads of bands with their sharp edges toward the region of shorter wave-length and shading off toward the red. The first five beginning at 3465 are the most distinct. Another series, much fainter, but of the same general character, appears below the copper line at 3247 (see Plate XXII, Fig. I).

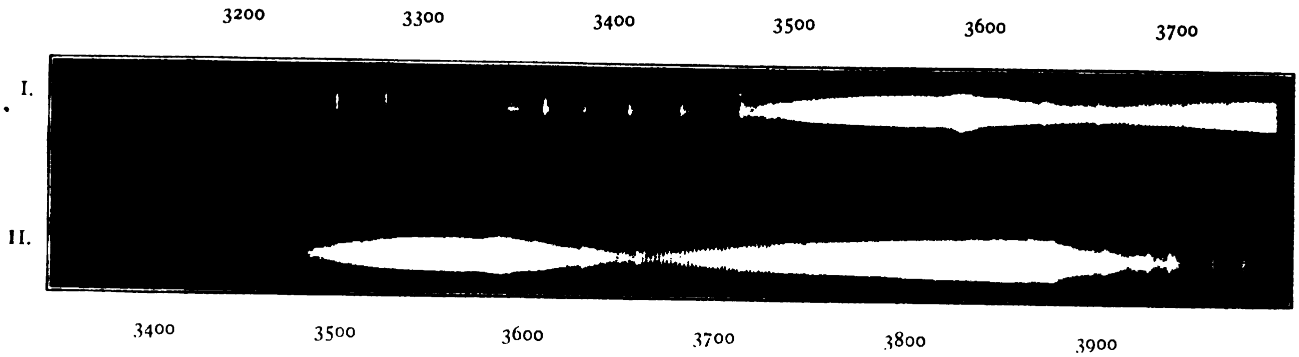
The wave-lengths of these two groups of apparent heads were computed by measuring their distances from the copper lines at 3247.65 and 3274.06 and taking these wave-lengths as a basis. In this way the following values were obtained:

Group I	Group II
3203.84	3465.69
3180.58	3433.17
3160.32	3405.04
3143.06	3380.58
3128.00	3360.27
	3340.64
	3322.40
	3296.48

Two questions in regard to these series must now be considered: (1) Are they really a part of the carbon spectrum or are they due to foreign matter? (2) May they not be caused by lines belonging to different heads of the known bands occurring close together or superposed at these points? We have the following evidence bearing on the first question: (1) The lines in this region have the same appearance as those in other parts of the carbon arc spectrum, and show a decided contrast to the sharp definition of the metallic lines due to impurities in the carbons. (2) With a long arc, the metallic radiation is strongest near one end of the arc, and the lines appear more intense at one side of the plate, while the series under discussion continue uniformly across the plate, as do the regular carbon bands. (3) Some of the plates were taken with very pure carbons prepared by a process to be described later, which gave no metallic spectra except traces of copper and calcium. (4) When the arc was surrounded by various gases, changing the intensity of some of the bands, the effect on these two series of bands was the same as on the two series with heads at 3590 and 3883. The evidence before us thus leads to the conclusion that the two series beginning at 3203 and 3465 belong to the same spectrum as the cyanogen bands at 3590 and 3883.

Taking up the second question, the idea that the banded appearance in the ultra-violet might be caused by an approach or superposition of lines belonging to different parts of the known bands was held by the writer at first, but it is not supported by the appearance of the banded structure. If it is caused by superposition of lines belonging to different heads, these heads would probably be those of the 3590 band. The new bands are at a considerable distance from the band at 3590. If, then, the successive lines of each of the heads belonging to the 3590 band become more and more separated as the distance from the head increases, as we should expect them to do, it is unlikely that there would be a sufficient number of lines in a short space to produce so dense an appearance, even if several lines belonging to different heads came close together in places.

PLATE XXII.



Spectrum of Cyanogen.

Besides, the structure in this region is very different from that in other parts of the spectrum where there are evidently superpositions of lines belonging to different heads.

It thus appears that the gradual separation of the lines as they recede from the head does not explain the occurrence of the dense portions at a distance from the head. Let us now see if the law of spectral series, so far as it has been worked out, affords any explanation of the observed structure. An article by Thiele in this JOURNAL, **6**, 65, 1897, offers a suggestion along this line by stating a mathematical condition which seems to be fulfilled in the structure of the cyanogen bands.

In this article, Thiele considers himself justified in asserting that an expression which shall give the wave-length of any line of a series as a function of the series-number n of the line must have the form $\lambda = f\left[(n+c)^2\right]$, where c is a constant which he calls the "phase" of the series. Taking this equation as a basis, he notes that if n be given successively all real integral values, λ will have a maximum and a minimum value at $\lambda_0 = f(0)$ and $\lambda_\infty = f(\infty)$ respectively. The physical meaning to be attached to these values is that in the neighborhood of λ_0 a finite number of lines are united in an ordinary head, while near λ_∞ an infinite number of lines are crowded into a finite space, that is, the region close to the value λ_∞. We should then expect a strong condensation near λ_∞, which Thiele calls the "tail" of the series. He then works out relations involving λ_∞, which, however, he does not apply to band spectra, and some of the constants used, notably n, the series number of a selected line, are very hard to determine in the case of band spectra. In Thiele's later article in this JOURNAL, **8**, 1, 1898, on series in the third carbon band, he does not consider the value λ_∞, and makes no attempt to locate the tail of this or of other bands. His object in this article is to find a formula giving the wave-length of any line in terms of its series number and constants.

It thus appears, if Thiele's hypothesis is correct, that each series should have a definite ending; that there should be a tail corresponding to each head in a band spectrum. The appearance and location of the band-like structure in the ultra-violet at once suggests the idea that these apparent heads are really the tails of the cyanogen bands at 3883 and 3590; and I wish besides to call attention to some simple numerical relations between these sets when considered as heads and tails; relations which, while they may not express the real law of the series, at least strengthen the idea that there is a definite connection between these different parts of the spectrum. The appearance of the two sets of tails has been described. The distance from the respective heads is such that we should expect the series belonging to the heads to be approaching the value λ_∞. There are five heads to the 3883 band, while there are eight tails in the group beginning at 3465. The first five tails, however, are much the stronger, and it is possible that the remaining three belong to weaker heads which are concealed by the dense structure of the 3883 band. The five tails in the group beginning at 3203, as compared with three heads in the 3590 band, may be accounted for in the same way.

Finding it impracticable to use Thiele's formulæ, owing to the difficulty in determining the constants, I have tried to find some numerical relation between these groups of heads and tails which would justify us in considering that they are connected in this way. It is found that the ratio of wave-lengths of corresponding heads and tails is constant. If we denote the wavelengths of the heads and tails of the 3590 band by h_n and t_n respectively, and those of the 3883 band by h'_n and t'_n, then

$$\frac{h_1}{t_1} = \frac{h'_1}{t'_1}, \quad \frac{h_2}{t_2} = \frac{h'_2}{t'_2}, \quad \text{etc.}$$

Or, substituting wave-lengths, we obtain the following table:

h_n	t_n	$\frac{h_n}{t_n}$	h'_n	t'_n	$\frac{h'_n}{t'_n}$
3590.52	3203.84	1.12069	3883.60	3465.69	1.12059
3585.99	3180.58	1.12746	3871.59	3433.17	1.12770
3584.10	3160.32	1.13409	3861.91	3405.04	1.13417

Comparing the third and sixth columns of this table, we see that the corresponding ratios agree to the third decimal place.

Let us now turn our attention to the spaces above 3590 and above 3883. In each of these regions we find three dense portions very similar in appearance to the tails which we have just discussed. If these were noticed by other observers, they were probably thought to be mere condensations due to the overlapping of the lines belonging to the heads above them. They have, however, the same diffuse appearance toward the red, with sharp edges toward the violet which we noticed in the tails above 3590. The structure in this region is shown in Fig. II. The wave-lengths of these two groups are as follows:

Group III	Group IV
3658.34	3984.93
3629.06	3944.91
3603.12	3910.45

Thinking that these may be tails belonging to the two cyanogen bands with heads at 4216 and 4606, I have tried the ratios found before to see if they will still hold. Taking the successive heads of these two bands and locating their tails by means of the ratios, we find that the tails belonging to the first three heads of the 4216 band should be at 3762, 3722, and 3684. These values fall in the dense portion of the 3883 band, and it cannot be decided whether the tails are really present or not. The same is true for the tails of the first three heads of the 4606 band. They should be at 4110, 4060, and 4014; but, if present, they are concealed by the dark ground in that region. The fourth, fifth, and sixth heads of the 4216 band, however, are in approximately the same ratio to the apparent tails in Group III that the heads of the same number in the 4606 band are to Group IV, thus $\frac{h_4}{t_4} = \frac{h'_4}{t'_4}$, etc.

h_n	t_n	$\frac{h_n}{t_n}$	h_n	t_n	$\frac{h_n}{t_n}$
4165.54	3658.34	1.13864	4532.06	3984.93	1.13730
4158.22	3629.06	1.14581	4514.95	3944.91	1.14450
4152.93	3603.12	1.15259	4502.35	3910.45	1.15136

It will be seen that the agreement between corresponding ratios is not as close as in the previous case, although it is still close enough to be of interest. The photographs show no signs of tails belonging to the so-called "carbon" bands at 4737, 5165, and 5635, the condensations which sometimes occur being evidently due to a superposition of lines belonging to different series.

This peculiar structure of the cyanogen bands was observed while studying the influence of various atmospheres on the carbon arc spectrum. I am still engaged on this work, but it may be of interest to give a short account of what has been observed thus far, with its bearing on the work of others.

It was desired to obtain carbons as free from metallic impurities as possible for this work, in order not only to produce a pure spectrum of carbon, but to eliminate any effects which the presence of metals might have on the character of the carbon spectrum. As commercial carbons contain many impurities, notably iron, I have made carbons from calcined sugar by a process which, if sufficient care be taken, produces a carbon free from all troublesome foreign matter. The sugar used should be chemically pure. Thus far I have recrystallized ordinary cane sugar; but a single recrystallization does not remove all traces of the copper and calcium used in refining sugar, and as a result my photographs show the H and K lines, also the strong copper lines at 3247 and 3274. These impurities can, however, be removed by repeated solution and crystallization.

The purified sugar was calcined in a covered porcelain crucible and the resulting charcoal ground to a fine powder. The cementing material used was a saturated solution of the pure sugar in distilled water. After adding to the powdered charcoal enough of this solution to form a thick paste, it was tamped into a solid rod in a clean brass mold. The carbon rod was taken from the mold and placed in an oven, heated gently until thoroughly dried, and finally baked at a red heat for at least two hours, in order that the sugar used in cementing might be completely calcined. The rods are then hard and last fairly well in the arc. They are, however, fragile, and are best used by fastening short pieces in the ends of metallic tubes.

The effects of atmospheres of carbon dioxide, nitrogen, and oxygen on the arc spectrum were observed. The arc was enclosed in a metallic chamber through which the gases were passed. Successive photographs of the same portion of the spectrum with the same time of exposure were taken with the arc in air and in the gas whose effect was being observed. In each case the so-called "carbon" bands at 4382, 4737, 5165, and 5635 were affected by the gas in a different way from the cyanogen bands at 3590, 3883, 4216, and 4606. The cyanogen bands were greatly weakened by the atmospheres of carbon dioxide and oxygen, as we should expect from the exclusion of the nitrogen of the air by these gases. The effect of oxygen was especially pronounced, the band at 4216 being entirely obliterated by this atmosphere. When a stream of nitrogen was passed around the arc, the cyanogen bands were slightly strengthened.

The effect of the three gases upon the "carbon" bands was the opposite of that observed with the cyanogen bands. The carbon bands were strengthened by carbon dioxide and oxygen, and weakened by nitrogen. When carbons containing metallic impurities were used in an atmosphere of oxygen, the metallic lines greatly intensified, many lines appearing which did not show at all on the plate taken in air with the same time of exposure.

Viewed in their bearing upon previous work on the carbon spectrum, these results strengthen the theory advanced by Liveing and Dewar[1] and later held by Kayser and Runge,[2] that the cyanogen bands are due to a nitro-carbon compound, though the theory of Foley[3] that nitrogen may produce this effect by its mere presence, without entering into actual combination, is worthy of consideration. As has been noted by Kayser and Runge and others, it is unlikely that cyanogen is the substance producing the bands, on account of the high temperature of the arc. The slight intensification when pure nitrogen was passed over the arc may be explained if the amount of this element in the air is sufficient to bring the bands almost to a maximum, so that the pure gas gives but a slightly increased effect. The effect of oxygen in strengthening the metallic lines was probably due to the increased rate of vaporization of the metallic impurities, as the carbons wasted away much faster in oxygen than in air.

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[1] *Proc. Roy. Soc.* 30, 33, 34.

[2] *Abh. Ber. Akad.*, 1889.

[3] *Phys. Rev.*, 5, 129, 1895.

The "carbon" bands have evidently a different origin from the cyanogen bands, since the two sets are affected in opposite ways by the same gas. The theory of Ångström and Thalén that the "carbon" bands are due to a hydrocarbon compound has not been disproved, since the apparatus used in my work would not exclude all hydrogen from the arc. While the possibility of such an origin must be admitted, the effect of carbon dioxide on the "carbon" bands serves to support the theory recently advanced by Professor Smithells[1] that these bands are due to carbon dioxide, since the atmosphere of oxygen might be expected to form carbon dioxide and produce the intensification which was observed with both oxygen and carbon dioxide. The weakening of the "carbon" bands by nitrogen would be the natural result of the exclusion of the oxygen of the air by nitrogen.

As has been noted earlier in this paper, the banded structure, supposed to be the tails of the cyanogen bands, is affected by the surrounding atmosphere in the same way as the heads of the cyanogen bands: a fact which serves to strengthen the belief that the apparent tails are a part of the nitro-carbon spectrum.

This work was carried on under the direction of Professor Percival Lewis, to whom I am indebted for much valuable advice and assistance.

UNIVERSITY OF CALIFORNIA,
November 1901.

[1] *Phil. Mag.* (6), 1, 476, 1901.

FOCAL SINGULARITIES OF PLANE GRATINGS.

By S. A. MITCHELL.

PECULIARITIES in the focus of the spectrum from a plane grating were first called to the attention of the writer by the spectroscope used in Sumatra at the eclipse of 1901.

Mr. L. E. Jewell and the writer together observed the eclipse of 1900 at Griffin, Ga., using a plane grating spectroscope without slit. Light was reflected horizontally from the coelostat mirror and fell on the grating, where it was diffracted, and brought to a focus by a quartz lens of fifty inches focal length, interposed between grating and photographic plate. Grating, lens, and plate were mounted in a box.

The spectroscopic work of the Naval Observatory eclipse expedition this year was under the direction of Mr. Jewell. He planned to use the same grating and same box, but with a quartz lens of seventy-two inches focus, instead of the one of fifty inches. The box was not long enough to permit the lens to be inserted between grating and photographic plate, and it was, therefore, placed in the incident beam of light, fourteen inches in front of the grating. Under the supposition that the action of a plane grating is equivalent to the combined actions of a plane mirror and a dispersing apparatus, it was thought that the spectrum would be brought to a focus fifty-eight inches from the lens, the combined distances making up the focal length of the quartz lens, or seventy-two inches.

Unfortunately, there was not sufficient time for Mr. Jewell to test the action of this arrangement at the Naval Observatory before leaving for the East.

This spectroscope was one of the instruments used by the writer at Sawah Loento, Sumatra, on May 18. After setting up the instrument, and attempting to adjust and focus with the assistance of Mr. Jewell, it was found that the spectrum was not brought to a focus in the manner expected, the focusing being accomplished with the help of a collimator which gave parallel beams of light, but from a slit source.

It was found that the "dust lines" caused by the slit, and the image of the slit caused by reflection from the grating were brought to a focus fifty-eight inches from the grating, but not so the spectrum. Making the grating normal to the incident light, and examining the spectrum of the first order from λ 3000 to λ 6000, it was found to be in focus from three to seven inches—depending on the color of the light—too far from the grating, the violet being brought to the shorter focus. If now the diffracted light is normal to the grating, and consequently, the first order on the other side is examined, the spectrum is focused from two to five inches too near the grating.

It was found impossible to use the spectroscope as arranged owing to the spectrum being so much inclined, and it became necessary to make an extension to the box to enable us to place the lens between grating and photographic plate. In this arrangement no difficulty was experienced in bringing the spectrum to a focus. Used in the latter manner, parallel beams of light are incident on the grating, and as parallel beams are diffracted.

This is the manner in which the plane grating is usually employed. To my knowledge, attention has not been called to the singularities in focus brought in by using a convergent pencil of light.

Since returning from Sumatra, my attention has been directed to an excellent article by M. A. Cornu[1] on, "A Study of Diffraction Gratings—Focal Anomalies," where he investigates the focal anomalies brought in through unequal ruling. Although he did not touch on the question of convergent light, its action can be readily found from the formula given there.

According to Cornu's equations, if the lines of the grating are equally spaced, and the radius of curvature is infinite, or the grating is plane, the equation in polar coördinates of the curve on which the spectrum is brought to a focus is:

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[1] *Astronomy and Astro-Physics*, 13, 207–215, 1894. *C. R.*, 116, 1215–1222, 1893. See also, KAYSER, *Handbuch der Spectroscopie*, 1. 441–446.

$$\frac{\cos^2\gamma}{R}+\frac{\cos^2\mu}{r}=0$$

or

$$r=-R\frac{\cos^2\mu}{\cos^2\gamma}.$$

Where R and r are the distances of the source and spectrum, γ and μ the angles they make respectively with the grating normal. It may be well to call attention to the fact that the above equation is independent of the grating space and of the size of the grating.

The above equation can be directly deduced from the theory of the concave grating, published by the writer,[1] by making in the equation of the focal curve the radius of curvature equal infinity.

The grating used had 15,000 lines per inch, with a ruled space of $3\frac{1}{2}\times 5$ inches. The quartz lens was a single lens of $3\frac{23}{64}$ inches aperture, made by Brashear.

The focal lengths of this lens for the different colors, according to Mr. Jewell, are as follows:

Wave-length	Focal-length	R
λ 3000	70.8263 inches	—56.8263 inches
λ 4500	71.8814 "	—57.8814 "
λ 6000	72.2768 "	—58.2768 "

As the source is virtual, the value of R is negative, and is found by subtracting fourteen inches from each of the focal lengths, as given above.

If in the equation of the focal curve, we put $R=\infty$, then $r=\infty$: the usual method of using the plane grating.

1. If the incident light is normal to the grating, $\gamma=0$; μ can be found from the ordinary equation of the plane grating:[2]

$$\sin\gamma+\sin\mu=\frac{n\lambda}{\omega},$$

where n is the order of the spectrum and ω the grating space.

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[1] ASTROPHYSICAL JOURNAL, 8, 105, 1898.

[2] See KAYSER, *Handbuch der Spectroscopie*, 1, 429.

If R is not equal to infinity, and we put, successively, values for R, γ and μ in the equation of the focal curve, we find the corresponding values of r, or the distances from the grating at which the spectrum is brought to a focus. We find these distances to be:

for λ 3000, $r=55.04$ inches
λ 4500, $r=53.70$ "
λ 6000, $r=50.95$ "

2. If the diffracted light is perpendicular to the grating, we get the "normal" spectrum. If $\mu=0$ for λ 4500, by inserting values of R, γ, and μ in the equation, as before, we find:

for λ 3000, $r=60.66$ inches
λ 4500, $r=62.17$ "
λ 6000, $r=62.21$ "

These values represent very closely the action of the grating noticed at the Sumatra eclipse.

Columbia University,
November 9, 1901.

ON THE HEAT-RADIATION OF LONG WAVE-LENGTH EMITTED BY BLACK BODIES AT DIFFERENT TEMPERATURES.[1]

By H. RUBENS and F. KURLBAUM.

As is well known, W. Wien[2] has derived, from thermodynamic considerations, the following formula, which gives the intensity, E, of the radiation of a black body for all wave-lengths, λ, and all temperatures, T,

$$E = C\frac{1}{\lambda^5}e^{-\frac{c}{\lambda T}} . \qquad (1)$$

More recently Mr. Planck[3] has established Wien's law upon an electromagnetic basis, so that the subject has become one of increased interest.

Up to the present, two experimental investigations of Wien's formula have been undertaken, one by Lummer and Pringsheim,[4] the other by Paschen[5] working alone, and at a later date working with Wanner. In the region of shorter wave-lengths and lower temperatures, the agreement among the results of these observers is satisfactory, but as wave-lengths become longer and temperatures higher, the discrepancies become more considerable. For instance, while Paschen always obtains exact agreement between his observations and Wien's formula, Lummer and Pringsheim find that for sufficiently high values of the product λT the deviations from this formula are very considerable. The contrast between theory and experiment is especially marked when one considers the so-called isochromatic curves, which express the intensity of radiation as a function of the temperature for any given wave-length. The equation of such an isochromatic curve is, according to Wien,

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[1] From the *Sitzungsberichte der Akad. Wiss. Berlin*, Oct. 25, 1900.

[2] W. WIEN, *Wied. Ann.*, **58**, 662, 1896.

[3] M. PLANCK, *Sitzungsberichte Ber. Akad.*, 1899, p. 440.

[4] O. LUMMER and E. PRINGSHEIM, *Verhandlung der Deutschen Phys. Ges*. I. Jahrg. S. 23 and 215, 1889; II. Jahrg. S. 163, 1900.

[5] F. PASCHEN, *Wied. Ann.*, **58**, 455, 1896; **60**, 662, 1897; *Berichte Berl. Akad.*, 1899, 405 and 959; *ibid.*, F. PASCHEN and H. WANNER, p. 5.

$$E = \text{const.}\ e^{-\frac{c}{\lambda T}}\ .$$

In order to represent their observations by this equation, Lummer and Pringsheim were compelled to assign a variable value to the quantity c, namely for

$\lambda = 1.2\mu$	2μ	3μ	4μ	5μ
$c = 13{,}900$	14,500	15,000	15,400	16,400

For still greater wave-lengths, it was found impossible to give an even approximate description of the isochromatic curve by means of a simple exponential function. For instance, the isochromatic curve for $\lambda = 12.3\mu$ calls for values of c which range from 14,200 to 24,000 as the temperature rises; while for $\lambda = 17.9\mu$ the values of c vary from 17,200 to 27,600.

Since, now, the quantity c enters Wien's expression as an absolute constant, it is evident from the experiments of Lummer and Pringsheim that this formula is not capable of describing the facts for longer wave-lengths and higher temperatures.

Thiesen[1] has recently proposed an empirical formula, which is based upon the observations of Lummer and Pringsheim for shorter wave-lengths ($\lambda < 7\mu$), and which appears to fit the facts much better than the law proposed by Wien.

Thiesen's expression is

$$E = C \cdot \frac{1}{\lambda^5} \cdot \sqrt{\lambda T} \cdot e^{-\frac{c}{\lambda T}}\ . \tag{2}$$

The one point of difference between this and Wien's equation is the presence of the factor $\sqrt{\lambda T}$.

Some months ago Lord Rayleigh[2] also discussed Wien's law of radiation, and pointed out the fact that it is inherently improbable, because for each wave-length it gives only finite values of intensity for infinite values of temperature. Rayleigh then proposed as a substitute

$$E = C \cdot \frac{1}{\lambda^5} \cdot \lambda T \cdot e^{-\frac{c}{\lambda T}}\ . \tag{3}$$

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[1] M. THIESEN, *Verhandlungen der Deutschen Phys. Ges.*, **2**, 37, 1900.

[2] RAYLEIGH, *Phil. Mag.*, **49**, 539, 1900.

Still a fourth general formula which includes the previously mentioned ones as special cases has been recently published by Lummer and Jahnke.[1] It runs as follows:

$$E = C \cdot \lambda^{-\mu}\, T^{5-\mu} \cdot e^{-\frac{c}{(\lambda T)^{\nu}}} \;. \tag{4}$$

Lummer and Pringsheim find that all of their observations which lie between $\lambda = 1\mu$ and $\lambda = 18\mu$ are in excellent agreement with this formula when $\mu = 4$ and $\nu = 1.3$. The difference between this expression and Lord Rayleigh's lies in the factor ν, which, in Rayleigh's equation, has the value unity. We have, therefore

$$E = C \cdot \frac{1}{\lambda^{5}} \cdot \lambda T \cdot e^{-\frac{c}{(\lambda T)^{1.3}}} \;. \tag{4a}$$

Finally, Planck,[2] since the completion of our experiments, has brought out a fifth formula, namely:

$$E = C \cdot \frac{\lambda^{-5}}{e^{\frac{c}{\lambda T}} - 1} \;. \tag{5}$$

For short wave-lengths and low temperatures this expression approaches Wien's; for long waves and high temperatures it is more nearly equivalent to Lord Rayleigh's; while it includes both as limiting cases.

Each of these equations, like that of Wien, implies Stefan's law of radiation, and also the following two relations,[3] which have been established by various observers, $\lambda_m T =$ constant and $\frac{E_{\text{max.}}}{T^5} =$ constant.[4]

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[1] O. LUMMER and E. JAHNKE, *Drude's Ann.*, 3, 283, 1900.

[2] M. PLANCK, *Berichte der Deutschen Phys. Ges.*, 2, Oct. 19, 1900.

[3] M. THIESEN, *ibid.*

[4] In each of the six equations given above the constant c has a different value, namely:

$$\left.\begin{array}{ll} \text{In Equation (1),} & c = 5\,(\lambda_m T) \\ \text{In Equation (2),} & c = 4.5\,(\lambda_m T) \\ \text{In Equation (3),} & c = 4\,(\lambda_m T) \\ \text{In Equation (4),} & c = \frac{\mu}{\nu}\,(\lambda_m T)^{\nu} \\ \text{In Equation (4a),} & c = \frac{1}{1.3}\,(\lambda_\mu T)^{1.3} \\ \text{In Equation (5),} & c = 4.965\,(\lambda_m T) \end{array}\right\} \lambda_m T = 2890.$$

For small values of the product λT, all of these formulæ give nearly the same series of values for E; but for high temperatures and long wave-lengths the differences which characterize these various equations show themselves in a marked manner. In this case, for instance, the exponential quantities $e^{-\frac{c}{\lambda T}}$ and $e^{-\frac{c}{(\lambda T)^\nu}}$ approach unity, and we have for the isochromatic curve, according to Wien, E=const.; according to Thiesen, E=const. $\sqrt{T}$; and according to Rayleigh, Lummer-Jahnke, and Planck, E=const.T. Now, in view of the fact that exact measurements are limited to temperatures less than 1500° C., it is evident that this case cannot be realized experimentally, that is, we cannot pass to wave-lengths so large, and to temperatures so high that the effect of the exponential quantity will completely disappear. Not only so, but there is a limit to the length of wave which can be measured with sufficient accuracy. However, it is always possible to go much farther in this direction by using the method of residual[1] rays than by ordinary processes of dispersion. We are, therefore, in a position to determine the fitness of these various formulæ in the region of larger wave-lengths.

At the suggestion of one of us, some measurements of this kind were carried out not long ago by Mr. Beckmann.[2]

He allowed the radiation from a black body to undergo reflection at four fluorite surfaces and then measured the intensity of the residual rays for various temperatures of the radiating black body.

As was shown not long since, there is a region in the infra-red — rather sharply limited — where fluorspar exhibits metallic reflection and in which two maxima occur, one at $\lambda = 24\ \mu$, the other at $\lambda = 31.6\ \mu$.

Experiment proves that after four reflections at fluorite surfaces there remain only such radiations of the black body as belong to the region of metallic reflection. This bundle of rays shows maxima of intensity at $\lambda = 24.0\,\mu$ and at $\lambda = 31.6\,\mu$. For the purpose of comparing observations with the above mentioned formulæ, we may assume that all the residual rays consist of two perfectly homogeneous radiations, one whose wavelength is $24.0\,\mu$, the other $31.6\,\mu$. Besides this, we must consider that the reflecting power of each fluorite surface at $\lambda = 21.6\mu$ is nearly 1.2 times as great as at $\lambda = 24.0\,\mu$, so that the relative intensity of the second band compared with the first is increased in the ratio $1.2^4 = 2.0$.

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[1] On the subject of residual rays, their production and their properties, see H. RUBENS and E. F. NICHOLS, *Wied. Ann.*, **60**, 418, 1897; H. RUBENS and E. ASCHKINASS, *Wied. Ann.*, **65**, 241, 1898; and H. RUBENS, *Wied. Ann.*, **69**, 576, 1899.

[2] H. BECKMANN, *Inaug. Dissert.*, Tübingen, 1898.

Beckmann, independently of the experiments of Lummer and Pringsheim, inferred from his own observations that Wien's formula could not correctly represent the facts by giving c the value 14500, which it has for short wave-lengths.

In order to obtain agreement between observed and computed values it was necessary to place[1] $c = 26000$. It was impossible for Beckmann to compare his results with the predictions of any others of the formulæ discussed in our introduction for the reason that these formulæ had not then been published.

And, indeed, Beckmann's observations were not very well adapted to test this law because the interval between his extreme temperatures is too small. The measurements begin at the temperature of solid carbon dioxide and end at about 600° C. While, as I have pointed out above, the characteristic features of these equations become marked only when we reach temperatures outside of this region and especially temperatures above this region.

We have therefore undertaken to measure the intensity of the residual rays from a black body throughout the largest possible range of temperatures. This research was made to include not only the residual rays of fluorspar but also those of rock salt which have a mean wave-length of $51.2\,\mu$. In this way we reached values of the product λT which are three times as great as those hitherto obtained by means of spectroscopic separation. The diagram given in Fig. 1 shows the disposition of our apparatus.

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[1] H. RUBENS, *ibid.*, p. 585. The fact that Beckmann was able to represent his observations by one of Wien's isochromatic curves is explained by the limited range of his temperatures.

D_1 is a double-walled diaphragm through which flows water at the temperature of the room, 20° C. The diaphragm is circular in form and the aperture one centimeter in diameter. This is mounted firmly upon the table and forms what is practically the source of radiation.

In front of this diaphragm is placed a black body *R* in such a way that its open end just fits into the aperture in the diaphragm and its axis stands at right angles to the plane of the diaphragm, adjustments which are secured by optical and mechanical devices. The rays which pass through D_1 traverse also a second diaphragm D_2, which limits the cone of rays in such a way that only those from the innermost part of the black body can get through. Farther on in the path of the rays is placed a double-walled screen, through which also flows water from the same supply as that in *D*. Still farther on in the path of the rays are the reflecting surfaces, *P*, of fluorspar or rock salt, as the case may be, a condensing mirror, *M*, silvered on the front, and the thermopile, *T*.[1] These latter parts of the apparatus are protected against outside radiation and air currents by being placed in a case. The thermopile was connected to a galvanometer of the shielded[2] form ("*Panzer Galvanometer*") whose sensibility was constantly under control by means of a simple

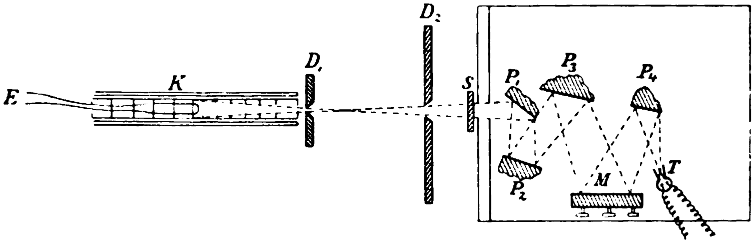

Fig. 1.

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[1] H. Rubens, *Zeitschrift für Instrumentenkunde*, 18, 65, 1898.

[2] H. du Bois and Rubens, *Drude's Ann.*, 2, 84, 1900.

device. Changes in sensibility were always taken into account in the computation of our results.

The impurities of the residual rays consist of heat rays which, in composition, are practically the same as the total radiation of the black body. Accordingly the intensity of the impurities must approximately obey Stefan's law and increase with the fourth power of the temperature, while the intensity of the residual rays varies directly as the first power of the temperature. It follows, therefore, that the relative impurity increases as the third power of the absolute temperature of the black body.

While four reflecting surfaces were found sufficient to isolate the residual rays of fluorspar with a fair degree of purity, it was discovered that this number of surfaces was not competent to separate the very weak residual rays of rock salt. By the use of five surfaces we obtained residual rays of satisfactory purity up to temperatures of 600° C., at which the impurity due to ordinary heat radiation amounted to 10 per cent. By the introduction of a sixth rock salt surface the impurity was reduced to about $\frac{1}{20}$. But at temperatures higher than 1000° C. it was again marked and at the highest attainable temperature 1474° C. amounted to almost 8 per cent. of the quantity being measured. We did not therefore attempt to further increase the number of reflecting surfaces, but preferred rather to determine exactly what correction was necessary to compensate for the impurity of the radiation. This was done by means of a rock salt plate which completely absorbed the residual rays while it transmitted 90 per cent. of the impurity.

In the experiments with fluorspar we employed four different black bodies which had already been used in other investigations at the Reichsanstalt.[1] The first of these (I) was a hollow radiating body so arranged as to be cooled by a stream of liquid air flowing over it. The second (II) was so arranged that it could be filled with solid carbon dioxide and ether. The third (III) was heated by steam, and the fourth (IV) by an electric current. This last was the only one used in the fluorspar experiments between 300° C. and 1500° C. In order to get the exceedingly feeble residual rays of rock salt, especially at low temperature and with sufficient accuracy, we removed the diaphragm D_1 (Fig. 1), and placed successively the first three of the black bodies immediately in front of the diaphragm D_2.

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[1] O. LUMMER and F. KURLBAUM, *Verhandlungen der Berliner Phys. Ges.*, 17, 106, 1898; and *Thätigkeitsbericht der Phys. Tech. Reichsanstalt*, p. 38. 1899.

This was admissible since these three black bodies each possessed an aperture greater than that of D_2. The electrically heated black body (IV) had an aperture of only 12 mm, so that we were compelled in this case to use also the diaphragm D_1 as indicated in Fig. 1.

We have therefore constructed for this investigation two more electrically heated black bodies which, like bodies I, II, and III, have sufficiently large linear apertures (30 mm) and emit sufficiently large cones of rays to be used immediately in front of diaphragm D_2.

One of these (V) was made of "Marquardt's substance" wrapped with a platinum band and could be used in the region of temperatures lying between 300° C. and 1500° C. The other (VI) was made of iron, blackened with iron oxide, and was heated by means of an electric current passing through a spiral of nickel. The highest temperature to which this body could be heated was 600° C. Accordingly it has been used only between temperatures 300° and 600° C.

As noted above, the black body IV was employed, in connection with the diaphragm D_1, for temperatures higher than 500° C. The deflection thus obtained was 7.5 times smaller than that obtained from bodies V and VI placed in front of diaphragm D_2. Deflections obtained with the body IV were therefore multiplied by this factor in order to make them comparable with other observations.

This numerical factor was determined by making the deflections due to bodies IV and V equal at a given temperature, approximately 1000°. On account of the smallness of the deflections produced by IV it is evident that the observations made on this body are much less accurate than the others. Nevertheless they are valuable as checks.

In Fig. 3 the points obtained by observation upon each of these different bodies are indicated by a different mark.

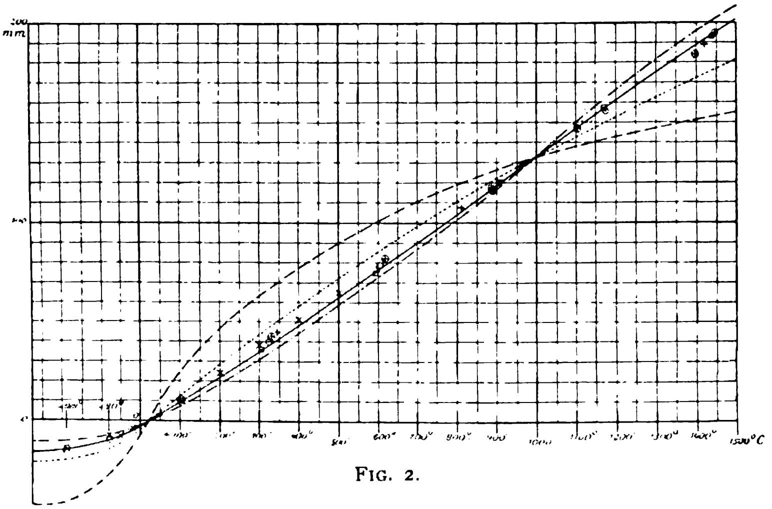

FIG. 2.

------ $E = f(t)$ calculated according to Wien.

.... $E = f(t)$ calculated according to Thiesen.

-.-.-.- $E = f(t)$ calculated according to Lord Rayleigh.

———— $E = f(t)$ calculated according to Planck.

× × × Observations of Beckmann.

● ● ● Observations of Rubens and Kurlbaum with sylvine plate.

+ + +
○ ○ ○ Series of observations of Rubens and Kurlbaum without sylvine plate with different adjustments of the fluorite surfaces.
□ □ □

In the case of the electrically heated bodies the temperatures were determined as usual by a Le Chatelier thermopile (E, Fig. 1) based upon the latest results of Holborn and Day.[1]

In Fig. 2 are shown the results of our observations on the residual rays of fluorspar, and in Fig. 3 those for rock salt, that is, the observed deflections are plotted as a function of the temperatures of the radiant bodies. And, by the use of different signs, four entirely independent sets of observations, made on different days and after independent adjustment of the fluorspar surfaces, are represented in Fig. 2.

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[1] L. HOLBORN and A. DAY, *Wied. Ann.*, **68**, 817, 1899.

In one of these sets where the individual observations are indicated by a point surrounded by a small circle (thus ⊙) a plate

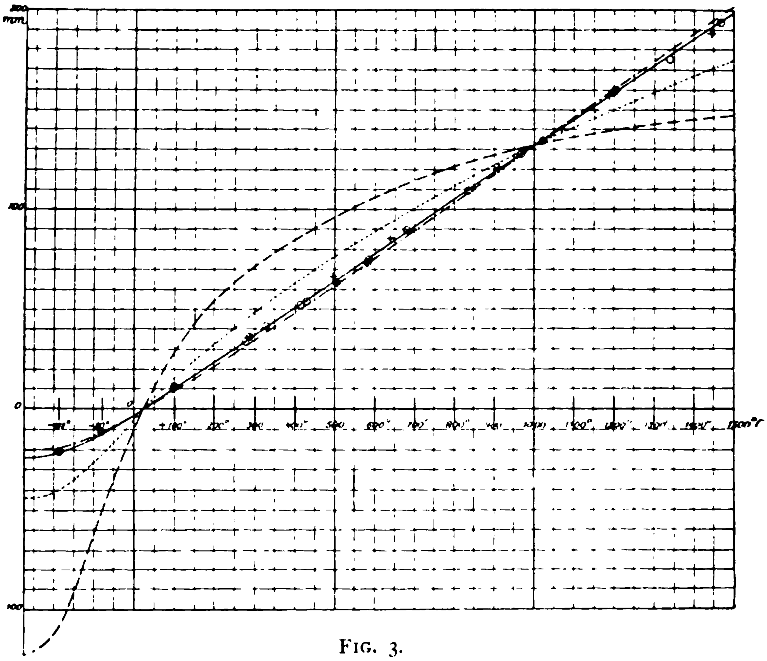

FIG. 3.

_ _ _ _ _ $E = f(t)$ calculated according to Wien.

. . . . $E = f(t)$ calculated according to Thiesen.

— — — — $E = f(t)$ calculated according to Lord Rayleigh.

———— $E = f(t)$ calculated according to Planck.

● ● ● Observed with Black Bodies I, II, and III.

○ ○ ○ Observed with Black Body IV.

✦ ✦ ✦ Observed with Black Body V.

○ ● ⊙ Observed with Black Body VI.

of sylvine 2 mm thick was placed in the path of the rays immediately in front of the thermopile. This served to completely absorb the long waves among the residual rays while it transmitted[1] nearly half of that radiation which has its maximum at $\lambda = 24.0\mu$.

In this manner the influence of the second absorption band was completely eliminated. Yet the results of this series show that the intensity of radiation varies with temperature in practically the same manner as when the plate of sylvine is not used. This series coincides however more exactly with the others when each ordinate is multiplied by the constant factor 2.80, as has been done in Fig. 2.

Finally a smooth curve—the solid line in Fig. 2—was drawn connecting all the points determined by observation. In the region of low temperatures (—188° to 0°) this curve exhibits marked curvature, being concave on the upper side. Farther on this curvature disappears almost completely and the curve becomes rectilinear. In other words, the residual rays between 0° and 1500° increase in direct proportion to the difference of temperature between the body which emits and the body which absorbs the radiation. The same is also true for rock salt, as is evident from Fig. 3, where the curve also begins with a slight concavity on the upper side and soon becomes rectilinear. For the sake of more easily comparing the curves of Figs. 2 and 3, we have given them each the same ordinate[2] at the temperature of 1000° C. And, as is evident, they differ very little for other temperatures.

In order to make possible a comparison of our results with those of Beckmann we have reduced his results to our scale and have plotted them in Fig. 2, where they are indicated by an asterisk (thus *). The agreement, as will be seen, is very satisfactory: and this coincidence is all the more important, since Beckmann's observations were confined to one black body while ours in the interval in question (—80° to 600°) were made upon three different bodies. It may therefore be considered as proved that the various bodies employed by us behave in the same way so far as an approximation to Kirchhoff's ideal black body is concerned. From Fig. 3, the same appears to be true also for rock salt. For here the black bodies IV, V, and VI give, within the limits of error, the same deflections throughout the range of temperatures in which they could be compared namely, from 275° to 600° and from 500° to 1500°.

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[1] H. RUBENS and A. TROWBRIDGE, *Wied. Ann.*, **60**, 724, 1897; also H. RUBENS and E. ASCHKINASS, *Wied. Ann.*, **65**, 253, 1898.

[2] The numerical value of the ordinates in the figures are so chosen that they are very nearly the actual deflection in millimeters produced by the residual rays of rock salt.

Besides the results of direct observation, Figs. 2 and 3 contain also three other curves showing the dependence of residual rays upon temperature, according to the formulæ proposed by Wien, Thiesen, and Lord Rayleigh. A fifth curve exhibiting this same function according to the formula of Lummer and Jahnke, using the constants $\mu = 4$ and $\nu = 1.3$, can be shown only for the lower temperatures, since it coincides almost perfectly with our observed curve. This is the formula which Messrs. Lummer and Pringsheim employed to represent their work. For the same reason it is impracticable to plot Planck's formula (5) in Figs. 2 and 3, since his expression agrees perfectly with our observations, not only from 0° to 1500,° but also from $-188°$ to 0°, at least to within errors of observation. The small deviations between our experimental results and the predictions of formulæ (4^a) and (5) may easily be seen from the following tables. The scales of all the curves are so chosen as to make the ordinates at 1000° exactly the same. In the computation of the curves for Fig. 2 we have always corrected for the presence of the band at $\lambda = 31.6\mu$, although the form of the curve would scarcely be affected if we were to neglect it entirely, and assume that the radiation is confined to a single band at $\lambda = 24\mu$. For temperatures above 0°, these deviations could scarcely be seen on the scale chosen for Fig. 2, since they are all less than 1 mm. They amount to an appreciable quantity only for very low temperatures, but for the sake of avoiding complication they are not shown in the diagram.

A glance at these curves is sufficient to prove that none of the formulæ of Wien, Thiesen and Rayleigh is capable of describing the results of observation within the limits of experimental error. Rayleigh's formula fits our results most closely, while that of Wein is the least adapted.[1] On the other hand, the deviations of our figures from the formula of Lummer and Jahnke (4^a) are very slight. These deviations become as great as the errors of observation only in the case of very low temperatures, where the deflections are 20 per cent. smaller than the computed values. For temperatures of the black body between 0° and 1500° C. the coincidence is perfect. We have already called attention to the fact that Planck's formula (5) describes our experiments for all temperatures.

In the two following tables are collected the interpolated values of the observed deflections for various temperatures, together with the values predicted by the formulæ (1), (2), (3), (4^a), and (5) both for the case of fluorspar and for the case of rock salt.

The most marked difference between formula and experiment is in the case of Wien's values for the residual rays of rock salt. At the temperature of liquid air the deflection observed is only about one-fifth of that computed, while, on the other hand, the deflection observed (194 mm) at 1474° is the

TABLE I.

Residual rays of fluorspar, $\lambda = 24.0\mu$ and 31.6μ.

Temperature Centigrade t	Absolute Temperature T	E Obs.	E according to Wien	E according to Thiesen	E according to Rayleigh	E according to Lummer and Jahnke	E according to Planck
− 273	0	....	− 42.4	− 20.7	− 10.7	− 17.8	− 15.4
− 188	85	− 15.5	− 41.0	− 20.2	− 10.5	− 17.5	− 15.0
− 80	193	− 9.4	− 26.8	− 14.0	− 7.4	− 11.5	− 9.3
+ 20	293	0	0	0	0	0	0
+ 250	523	+ 30.3	+ 50.6	+ 35.7	+ 25.3	+ 30.0	+ 28.8
+ 500	773	+ 64.3	+ 88.9	+ 71.8	+ 58.3	+ 64.5	+ 62.5
+ 750	1023	+ 98.3	+114	+104	+ 94.4	+ 98	+ 96.7
+1000	1273	+132	+132	+132	+132	+132	+132
+1250	1523	+167	+145	+157.5	+174.5	+167	+167.5
+1500	1773	+201.5	+155	+181	+209	+201	+202
+ ∞	∞	....	+226	+ ∞	+ ∞	+ ∞	+ ∞

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[1] The single point of intersection chosen for these curves, namely, $t = 1000°$ C. is selected for the purpose of making the divergence between theory and experiment as small as possible. If these curves had been made to coincide at $t = 1500°$ C., the discrepancy would have been much more marked.

TABLE II.

Residual rays of rock salt, $\lambda = 51.2\mu$.

Temperature Centigrade t	Absolute Temperature T	E Obs.	E according to Wien	E according to Thiesen	E according to Rayleigh	E according to Lummer and Jahnke	E according to Planck
− 273	0	....	−121.5	− 44	− 20	− 27	− 23.8
− 188	85	− 20.6	−107.5	− 40	− 19	− 24.5	− 21.9
− 80	193	− 11.8	− 48.0	− 21.5	− 11.5	− 13.5	− 12.0
+ 20	293	0	0	0	0	0	0
+ 250	523	+ 31.0	+ 63.5	+ 40.5	+ 28.5	+ 31	+ 30.4
+ 500	773	+ 64.5	+ 96	+ 77	+ 62.5	+ 65.5	+ 63.8
+ 750	1023	+ 98.1	+118	+106	+ 97	+ 99	+ 97.2
+1000	1273	+132	+132	+132	+132	+132	+132
+1250	1523	+164.5	+141	+154	+167	+165.5	+166
+1500	1773	+196.8	+147.5	+175	+202	+198	+200
+ ∞	∞	... ...	+194	+ ∞	+ ∞	+ ∞	+ ∞

limiting value set by Wein's formula for an infinitely high temperature, assuming the scale which we have here employed.

In any event, it is evident from the preceding results that only those formulæ which make the radiation E vary directly as the temperature T, are competent to describe the behavior of a black body for large wave-lengths and high temperatures. Such formulæ are those of Lord Rayleigh, Lummer Jahnke ($\mu = 4$) and Planck.

Of these three formulæ, however, only the last two are to be considered, since Lummer and Pringsheim have shown that Rayleigh's expression does not represent the facts in the case of short wave-lengths. In comparison with our observations, also, it shows considerable systematic deviation. We find, therefore, that so far as the representation of Lummer and Pringsheim's results, as well as our own, is concerned, the formulæ (4^a) and (5) are excellently adapted, but that Planck's expression, in so far as it does the same thing, deserves the preference on account of its simplicity.

[Shortly after the publication of this article in the *Proceedings of the Berlin Academy*, it appeared in a somewhat amplified form in *Drude's Annalen*, **4**, 640–660 (1901). The principal change from the present article consists in addition of an isochromatic curve for wave-length $\lambda = 8.85\mu$, determined by the measurement of residual rays reflected from quartz. The isochromatic thus obtained confirms the conclusions which the authors had already drawn from their observations on rock salt and fluorspar.]—ED.

MINOR CONTRIBUTIONS AND NOTES

PRELIMINARY REPORT OF OBSERVATIONS OF THE TOTAL SOLAR ECLIPSE OF 1901, MAY 17–18.[1]

THROUGH the generosity of Mr. William H. Crocker, of San Francisco, it was possible for the Lick Observatory to send an expedition to Sumatra to observe the total solar eclipse of May 17–18, 1901, thus continuing, unbroken, the series of expeditions begun upon the opening of the Observatory in 1888.

The great duration of the eclipse and the high altitude of the Sun promised many advantages in the solution of a number of problems, and rendered it extremely desirable to take advantage of the event.

The expedition left San Francisco on February 19, traveling by the regular lines of steamers, and reached the city of Padang, on the west coast of Sumatra, on April 5.

After consulting with the Dutch officials, the abandoned race-course in the northern portion of Padang was selected as a site for the station. Its approximate position was

Longitude $6^h\ 41^m\ 20^s$ East of Greenwich.
Latitude $0^\circ\ 56'$ South.

The work planned for was as follows:

1. Large scale photographs of the corona with the fixed telescope of 40 feet focal length, designed and used first by Professor Schaeberle in Chile in 1893.

2. Photographs of the corona with the Floyd telescope of 5 inches aperture and 70 ± inches focal length.

3. Photographs of the corona with the Pierson[2] (Dallmeyer) camera of 6 inches aperture and 32.6 inches focal length.

4. Photographs in duplicate of the region about the Sun, for the detection of any small planets with orbits interior to that of *Mercury*. These photographs were to be secured with four telescopes of 3 inches

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[1] *Lick Observatory, University of California, Bulletin* No. 9.

[2] This portrait lens is the property of Hon. W. M. Pierson, of San Francisco, and has been very kindly loaned by him for a number of eclipse expeditions.

aperture and 11 feet 4 inches focal length, covering a region 18° on either side of the Sun in the direction of its equator and 5½° wide.

5. A single photograph of the spectrum of the corona with a spectrograph containing one light flint 60° prism, and having the slit north and south across the corona about 2′ east of the Sun's east limb.

6. A single photograph of the spectrum of the corona, using a spectrograph similar to the preceding, but with the slit directed east and west across the Sun's center. Both of these instruments were designed especially to record any Fraunhofer lines existing in the corona.

7. Photographs of the entire corona with a camera of 20.75 inches focal length, having a double image prism of 1 inch aperture placed in front of the objective. Two exposures were to be made in each of five positions of the prism, 22½° apart, the first exposure being made with the principal plane of the prism parallel to the Sun's equator.

These photographs should show polarization in the light of the corona, if any appreciable percentage were polarized in a given plane.

The 40-foot telescope was mounted as at former eclipses, *i. e.*, pointing directly at the Sun.

The four intra-mercurial telescopes were fastened together rigidly, and mounted equatorially. As the position of the telescopes had to be changed during the eclipse to cover different regions of sky not along the direction of diurnal motion, they were mounted directly on a second axis perpendicular to the plane of the Sun's equator.

The remaining five instruments were all attached to a long polar axis, and driven by one clock.

All of the ten instruments were mounted and in adjustment by May 12. The remainder of the time before the eclipse was devoted to drilling the observers, to checking the many adjustments of the various instruments, and to the arrangement of the final details.

Eclipse day dawned with a sky covered with light cirrus clouds, which condition continued with but little variation throughout the morning. At the time of first contact the Sun shone through an almost clear space between clouds. As totality approached, a clear sky was visible off near the northern horizon, but light clouds and haze still covered the sky above our station. The clouds were considerably thicker toward the end of totality than they were during the first half, all of the corona negatives showing marked diminution in light. Shortly after totality the clouds began to dissipate, and before 2 o'clock the sky overhead was perfectly clear.

While the clouds interfered to a certain extent with some of the observations, others have proved to be as satisfactory as if the sky had been perfectly clear. The negatives of the inner and middle corona, with both the 40-foot and the Floyd telescopes, show all the detail that would have been secured in a clear sky. The same is equally true of the polariscopic and spectroscopic results. In fact, the cloudiness was a benefit, rather than a detriment, to these last investigations, bringing out some features which otherwise would have been lost through over-exposure.

The intra-mercurial planet search suffered the most severely from the clouds, but the plates will perhaps enable a more far-reaching conclusion to be drawn as to the maximum brightness which any such bodies can have, than has heretofore been possible,

The apparatus and the negatives were shipped from Padang on May 29, and in the natural course of events should have reached home before August 1. Unfortunately, the packages were delayed at some port en route, at present unknown, and did not arrive at Mount Hamilton until October 11. The photographs made the trip without accident, and are all in good condition.

The complete program of observation, with a brief preliminary statement of the results secured, is given below.

LIST OF NEGATIVES.

No.	Instrument	Size of plate	Kind of plate	Exposure	Remarks
1	40-foot camera	8 ×10	Carbutt B	½^s	Good.
2		14 ×17	Seed 27	1	Good. Detail off E. limb well shown.
3		14 ×17	Seed 27	2	Good. Detail off E. limb well shown.
4		14 ×17	Seed 27	4	Good. Corona to 15′.
5		14 ×17	Seed 27	16	Good. Corona to 15′.
6		18 ×22	Seed 27	40	Good. Corona to 20′.
7		18 ×22	Seed 27	150	Good. E. streamer to fully one and one-third diameters.
8		14 ×17	Seed 27	4	Good. But little corona.
9		14 ×17	Seed 27	25	Good. About the same extension as No. 3.
10		14 ×17	Seed 27	8	Good. Much less than Nos. 3 and 4.
11		14 ×17	Seed 27	1	Good.
12		8 ×10	Carbutt B	½	First flashes of returning sunlight.
1	Floyd, 70-inch	5 × 7	Seed 27	½	Good. Streamers to 10′.
2			Seed 27	2	Good. Eastern extension to one diameter
3			Seed 27	8	Good.

LIST OF NEGATIVES.—*Continued.*

No.	Instrument	Size of plate	Kind of plate	Exposure	Remarks
4	Floyd, 70-inch	5 × 7	Seed 27	4	Good. Streamers to 25′.
5			Carbutt B	60	Good. Streamers to over a diameter.
6			Seed 27	20	Good. Extensions only 15′.
7			Seed 27	2	Good. Extensions only 5′.
8			Seed 27	½	Good.
1	Pierson (Dallmeyer)	8 × 10	Seed 27	½	Eastern streamers to one diameter.
2			Seed 27	2	Eastern streamers to one diameter.
3			Seed 27	8	Eastern streamers to one diameter.
4			Carbutt B	30	Over-exposed.
5			Seed 27	4	Slide not drawn.
6			Carbutt B	60	Over-exposed. E. streamer to 1¼ diam.
7			Seed 27	20	Slide not drawn.
8			Seed 27	10	Corona to 20′.
9			Seed 27	2	Caught by returning sunlight.
10			Seed 27	½	Not exposed.
A 1	Intra-mercurial	14 × 17	Seed 27	90	28 stars. Faintest = 8.8 visual magnitude.
B 1					
C 1					37 stars. Faintest = 8.6 visual magnitude.
D 1					
A 2				90	27 stars. Faintest = 8.8 visual magnitude.
B 2					
C 2					No star images.
D 2					
A 3				75	No star images. Inner corona and *Mercury* and *Venus* are distinct.
B 3					
C 3					No star images.
D 3					
1	Spectrograph I (Slit tangential)	2⅛× 3¼	Cramer Crown	320	Good.
1	Spectrograph II (Slit Radial)	2⅛× 3¼	Cramer Crown	320	Good.
1	Polarigraph Setting 0°	3¼× 4¼	Cramer Cr.	1	Negative good.
2				10	Slide not drawn.
3	22½			1	Negative good.
4				10	Negative good.
5	45			1	Negative good.
6				10	Negative good.
7	67½			1	Negative good.
8				10	Negative good.
9	90			1	Negative good.
10				10	Negative good.

PHOTOGRAPHS OF THE CORONA.

The negatives secured with the 40-foot and Floyd telescopes show the inner corona as well probably as if there had been no clouds to interfere; but the longest recorded streamers are limited to about one and one third solar diameters. The corona is of the minimum type. Without describing the photographs in detail, attention may be called to an especially conspicuous series of coronal hoods surrounding a prominence in position angle 115°, and to a remarkable disturbance in the northeast quadrant of the corona. The latter is near position angle 65°. At this point on the limb is a small compact prominence, over which there is a disturbed area resembling roughly an inverted cone of large solid angle. The apex of this area is not visible; it seems to lie below the chromospheric layer showing at the limb, as if the apex were at some distance in front of or behind the limb. From the apparent position of the apex a number of irregular streamers and masses of matter radiate as if thrown out by an explosion. A long thread-like prominence to the south of this point appears to emanate from the same source. The corona above and around this region is composed of broken, irregular masses, much like those seen in photographs of the Orion and other similar nebulæ. So far as I am aware, no such disturbance in the corona proper has been observed before.

INTRA-MERCURIAL PLANET SEARCH.

The results given in the table for the intra-mercurial plates are derived from an inspection at the station in Sumatra. A more thorough examination will be given them later. It is possible that more stars will be found, and that some images may be detected on the negatives marked as having none.

The performance of these lenses[1] has been very satisfactory. There is but little distortion on any part of a 14 × 17 plate; and, with a clear sky, stars of 9½ to 10 magnitude could undoubtedly have been photographed in the 90 seconds. A 4-inch aperture of the same focal length could be used without the darkening of the plates becoming objectionable in exposures of two minutes or less, and with considerable gain in light power.

POLARIGRAPH.

The first exposures secured with this instrument show the equatorial extensions of the corona to a distance of one diameter; toward the end of totality only about one quarter of a diameter is shown, owing to increased cloudiness.

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[1] These lenses for intra-mercurial planet work were designed by Professor W. H. Pickering. Two of those used in Sumatra were loaned by Professor E. C. Pickering, Director of the Harvard College Observatory.

The negatives indicate a large percentage of polarization in the light of the corona beyond 10′ from the solar limb. This is true of all position angles, including the regions containing the polar streamers.

The last exposures point to a relatively small amount of polarized light in the inner corona.

SPECTROGRAPHS.

The two spectrographs (as well as the polarigraph) were designed and prepared for use by Director Campbell and Assistant Astronomer W. H. Wright. The negatives secured show both instruments to be very efficient for the purpose of recording dark lines in the spectrum of the corona. Had the sky been free from clouds the spectrum of the inner corona would have been over-exposed.

Spectrograph with tangential slit.— The slit was placed north and south across the corona about 2′ east of the Sun's east limb. The negative shows a width of spectrum of rather over a solar diameter and covers the region from λ490 to λ360 ±.

The H and K lines are bright and quite strong, the latter having the greater intensity. No doubt these are due to calcium radiations from the prominences diffused in our sky. No other bright lines are shown. The continuous spectrum is strong, but not so dark as to obliterate the details. There are several stronger bands extending longitudinally through the spectrum, which are due in all probability to the brighter condensations in the corona proper. Many Fraunhofer lines are visible, especially between $H\gamma$ and K, and can be traced across the full width of the spectrum. They are less distinct where they cross the dark belts mentioned above. The disturbed area already spoken of fell across the slit of this spectrograph. Comparisons with a sky spectrogram secured with the same instrument show that the coronal and sky spectra are sensibly identical in the blue and violet regions.

Radial slit spectrograph.— In this spectrograph the slit was placed east and west across the Sun's center. The negative shows practically the same range of spectrum as the preceding one, and extends on either side of the Moon's disk to over a diameter. The image of a prominence on the east limb of the Sun covered the slit, producing very bright over-exposed H and K lines, as well as the other characteristic prominence lines. On either side of the Moon's disk is a band of continuous spectrum about 8′ in width without any trace whatever of dark lines. Outside of this band 35 Fraunhofer lines can be counted between $H\beta$ and H, extending out to the limit of the spectrum. The dark lines visible lie almost wholly between these limits, beyond which there is but little trace of the spectrum of the outer corona. A longer exposure would probably have shown all the Fraunhofer lines observable with the slit-width and dispersion used. As in the case of the other spectrograph, a comparison was made with a negative of the sky taken with the same instrument, and the same agreement was noted.

Bright H and K lines of good strength extend entirely across the Moon's disk, and to a distance of about 40′ east of the Sun's limb, but they show only feebly on the west side of the Sun. They are symmetrical with reference to the image of a prominence on the east limb, indicating a diffusion in our atmosphere of calcium radiations from that source. A consideration of all the facts shows that the clouds have not affected these results, nor their interpretation.

Professor Campbell has examined these spectrograms, and confirms the above results.

It should be noted that Professor Campbell's spectrographic observations at the India eclipse of 1898 also showed no trace whatever of dark lines in the inner corona, the spectrum only extending to a distance of 2′.5 from the limb, however. The Indian results were obtained with high dispersion, using four light prisms in one case, and six dense prisms in another.

The preceding observations seem to point to a very definite explanation of the general constitution of the Sun's corona. The spectroscopic and polariscopic results agree in showing that the light of the outer corona is in great measure reflected sunlight, whereas the spectrograph shows the light from the inner corona to emanate largely from incandescent matter. These facts, taken in connection with the varying appearance of the corona, suggest as the most reasonable explanation that matter, probably very finely divided, is ejected from the surface of the Sun with great velocity, giving rise to the streamers and extensions observed. This matter may or may not be solid when it first leaves the Sun, but observation indicates that it is incandescent, and probably largely solid, when it first becomes visible above the layer of chromosphere. While in this state, its inherent light would in all probability be much greater than the light reflected from the solar surface; but a point would be reached in its outward journey where it would become cool enough for the reflected light to be observable. While actual radial motion has not been observed in the corona proper, appearances point far more strongly to a condition of great movement than to a state of comparative rest.

The well-known bright lines observed on many occasions in the corona indicate, also, an irregular but comparatively thin gaseous envelope about the Sun. However, the quantity of light contained in the bright-line spectrum is very small in comparison with that composing the continuous spectrum; and it is probable that the gaseous envelope does not appreciably affect the ordinary photographs of the corona.

It should be noted that the explanation suggested above, deduced through a different train of reasoning, from an entirely distinct set of facts, is in accord with the conclusion reached by Professor Schaeberle from a study of the forms of the coronal streamers shown in his large scale photographs of the 1893 eclipse, that these streamers are composed of matter ejected from the Sun, with great velocity.

TIMES OF CONTACTS.

The first three contacts were observed by me as follows;

	h	m	s	
I	22	45	30.9	mean time of station.
II	0	18	52.3	
III	0	25	1.3 ± 1^s	

Observed duration of totality, $6^m\ 9^s.0$.

The following are the times of the contacts for the station, computed from the data given in the American *Ephemeris*:

		d	h	m	s	
Beginning of eclipse	May	17	22	45	16.1	mean time of station.
Beginning of totality	May	18	0	18	49.9	
End of totality	May	18	0	24	56.8	
End of eclipse	May	18	1	57	25.5	

Computed duration of totality, $6^m\ 6^s.9$.

Contact I was observed with the sextant, and is probably 2^s or 3^s later than geometrical contact. Contacts II and III were observed without optical aid. Contacts I and II were timed directly from the chronometer; contact III, by means of the counts of the timekeeper, and is subject to a possible uncertainty of a second. As soon as possible after totality, the counts were compared directly with the chronometer. The corrections to the chronometer were determined from sextant observations of the Sun.

The time observation secured after the eclipse indicated a considerable change of rate of the chronometer subsequent to the observation of the same morning. About ten minutes before the beginning of totality the chronometer was removed from the shelter, where it had remained undisturbed on a pier, in order to permit the timekeeper to have a view of the eclipse, and replaced in its original position shortly after totality. In determining the chronometer corrections for the times of the contacts, it has been assumed that the change of rate occurred with the change of position of the chronometer.

SHADOW BANDS.

The conditions of the sky were unfavorable for observations of the shadow bands. Mr. Lagerwey, however, detected faint bands at the beginning of the eclipse. These bands had wavy outlines at first changing to almost straight toward the end of their apparition. The direction of the wave front was north 60° east and south 60° west, the waves moving in a direction at right angles to the wave front.

THE GREAT SOUTHERN COMET.

On May 4 a telegram was received from Professor Skinner announcing that a brilliant comet had been observed by Mr. Dinwiddie at Solok, in the western sky just after sunset of the previous evening. The evening of May 4 was cloudy at Padang, but the evening of May 5 was clear; and the comet was seen low in the west against a very bright sky. Sextant observations were secured of its position, using the nearest available stars. As the sky darkened, it became a very conspicuous object. It had a brilliant nucleus, and a tail 6° to 8° in length. The Pierson camera was mounted on the following day and directed to the place of the comet. Owing to the brightness of the sky and to the lack of means for following the comet, only short exposures were attempted. Four negatives were secured on May 6, as follows:

	Duration of exposure	Length of tail
No. 2_2	1 m	3°
4_2	3	3½
1_4	7	4
1	0 m 30 s	

The last plate contained no image owing to the haze and the proximity of the comet to the horizon.

The principal tail was composed of two slightly curved and nearly parallel streamers. The second and third negatives show a very faint streamer to the south, making an angle of 35° with the axis of the principal tail.

Clouds near the western horizon prevented any further observations or photographs, although the instruments were left in readiness, until it became necessary to adjust them for the eclipse.

Mr. Ralph H. Curtiss, formerly assistant in the Students' Observatory, University of California, was appointed assistant in the Lick Observatory from February 15, and accompanied the expedition, helping throughout in the work of preparing the station and in the observations.

The most cordial aid was extended to the expedition in all possible ways by the officials and citizens of Padang, and I am largely indebted to them for the results obtained. Especial thanks are due to His Excellency, Governor Joekes, for information and introductions to heads of departments, as well as for protection during our stay; to Kolonel H. F. C. Van Bijlevelt, commander of the army in Sumatra, who detailed a number of his officers to take part in the observations; to Major Muller, of the general staff N. I. army, for advice as to the choice of a station ; to Assistant Resident Hartogh Heiss, head of the police department of Padang, who obtained trustworthy watchmen, conducted some of the business negotiations, furnished a large detail from his force to do guard duty on the day of the eclipse, and had the immediate responsibility for the safety and quietness of the camp ; to Heer Th. F. A. Delprat, head of the government railways of Sumatra, for free transportation for observers and freight, for the detail of skilled workmen from the very extensive railway shops, for the facilities of a complete photographic dark room, for his assistance throughout the observations and for his counsel and help in practical matters at all times ; to Heer F. Bouman, superintendent of construction of the railways, for his oversight of the construction of the necessary structures and shelters required at the station, as well as for his assistance throughout the observations.

Those who took part in the work of observation were: Heer Th. F. A. Delprat; First-Leutenant der genie P. L. de Gaay Fortman ; Second-Leutenant der Infanterie W. H. Warnsinck; Second-Leutenant der

Infanterie E. Sieburgh; Mevrouw de Gaay Fortman, Heer J. Kempens, Heer F. Bouman, Heer van Leeuwen Boonkamp, Heer van der Straeten, Heer Junius, Heer Cleton, Heer Nieuwenhuys, Heer Guldenaar, Heer d'Hanens, and Heer Lagerwey.

The greatest enthusiasm was manifested by all in the preliminary rehearsals as well as in the observations on eclipse day.

Favors were shown to the expedition in all possible ways, from Mt. Hamilton to Padang, every one being not only willing but anxious to aid. Among these especial mention should be made of Mr. Robert Bruce, of the firm of Balfour, Guthrie & Co., of San Francisco; the Toyo Kisen Kaisha; the Occidental and Oriental Steamship Company; the Pacific Mail Steamship Company; the officers of steamship "Nippon Maru;" and Mr. Aubrey Fair, of Hongkong; Mr. A. I. Ross and Mr. T. Scott, of the firm of Guthrie & Co., Singapore; the agents and officers of the "Koninklijke Paketvaart-Maatschappij" and "Stoomvaart Maatschappij Nederland;" the representatives of the firm of J. Daendels & Co., in Singapore, Batavia, and Padang; the officers of the Hongkong and Shanghai Bank, in San Francisco and Batavia, and of the Java Bank in Padang; Heer C. G. Veth, the American Consul in Padang.

It is planned that a full report of the observations, with reproductions of some of the photographs, shall appear as early as possible, in a volume of the publications of the Lick Observatory.

C. D. PERRINE,
In charge of Expedition.

OCTOBER 14, 1901.

MOTION IN THE FAINT NEBULA SURROUNDING *NOVA PERSEI*.[1]

PHOTOGRAPHS of *Nova Persei* were obtained with the Crossley reflector by Messrs. H. K. Palmer and C. G. Dall between February 24 and March 29 inclusive, all of short exposure. It was planned to make a long exposure of the region about the *Nova*, but this was not done until the nights of November 7 and 8, as the telescope was used for spectroscopic work during the summer months. An exposure of $4^h\ 19^m$ was secured on the night of November 7, and 3^h on November 8, making a total of $7^h\ 19^m$. The exposure on the latter night was stopped by the fog, which had been in the cañons and valleys, rising around the mountain top.

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[1] *Lick Observatory, University of California, Bulletin* No. 10.

I had hoped to give an exposure of ten hours, but as the storm promised to be an extended one, I developed the plate on the following day. The seeing on the first night was excellent; on the second night it was only fair to start with, and toward the end became very bad at times. The resulting negative is not entirely satisfactory, the star images being somewhat elongated owing to the unstable mounting of the instrument, and blurred by the intervals of poor seeing. The large mirror has not been resilvered since it left England in 1895, so that considerable light is lost at this surface.

The plate used was a Seed 27 of a fresh emulsion. The negative shows but little fogging from the general illumination of the sky. Upon it are to be seen the nebula south of the *Nova* discovered by Professor Max Wolf[1] and most of the nebulosity shown on the photograph and drawing of Mr. Ritchey's negative.[2] The strongest nebulosity is very near to the *Nova*, adjoining it on the south and west. This mass is elongated in a general direction south of east and is nearly two minutes of arc in length. There are a number of very faint wisps to the south of the *Nova* for a distance of 6′, the outer ones being the stronger. These outer wisps are concave toward the *Nova*, on the arc of either a conic section, other than a circle, or of a spiral; but as only the outer end can be traced, the form of the curve remains undetermined. To the north of the *Nova*, and seeming to join it, there is a faint mass of nebulosity, while farther away in the same direction are traces of other masses, but they are too faint to make any structure certain. The image of *Nova* on the negative is 40″ in diameter.

A comparison of this negative with the reproduction from the photograph secured by Mr. Ritchey with the two-foot reflector of the Yerkes Observatory, on September 20, reveals some remarkable changes of position in the more pronounced condensations. Only four of these condensations are sufficiently defined to make determinations of position certain enough for purposes of comparison.

The accompanying diagram was made by taking a tracing of Mr. Ritchey's photographic reproduction (the fainter stars are not included), the centers of figure of the four condensations being indicated thereon by dots. The centers of figure of these same condensations were then indicated in a similar way on the back of my negative and transferred to the tracing.

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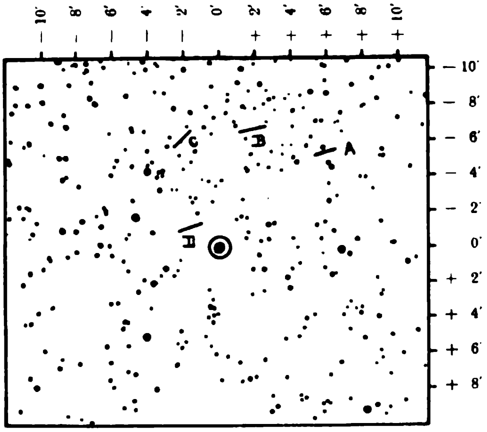
[1] *Astronomische Nachrichten*, No. 3736.

[2] ASTROPHYSICAL JOURNAL, 14, 167.

The four masses of nebulosity used are designated by the letters *A*, *B*, *C*, *D;* the positions which the centers of figure occupied on September 20, as shown in the reproduction from Mr. Ritchey's photograph, are occupied by the left-hand or northwest end of each of the short lines; the positions on November 7 to 8 are occupied by the right-hand or southeast ends of the lines.

The line drawn between these positions for each condensation indicates the direction and amount of motion in the interval of forty-eight days. Condensation *A* is much the best adapted for accurate measurement, from its greater strength and from its forked appearance; condensations *B* and *C* are not quite so good for measurement as *A*, but still are very determinate; but while condensation *D* is the brightest of all, it is large and so near the image of the *Nova* as to make its amount and direction of motion somewhat uncertain.



It will be seen that the displacements agree well, and amount to about 1½′. The directions are not so consistent, and could perhaps be explained by irregular motions in the nebulous mass, by a general translation of the nebula in one direction, or by a spiral motion. It is certain, however, that the motion is not radial.

The amount of motion is almost incredible, being no less than at the rate of 11′ per year. The greatest displacement (proper motion) in the stellar universe so far observed is less than 9″ per annum.

Such an exceptional velocity as is here indicated leaves little doubt of the intimate connection of this nebulous matter with the *Nova* and its outburst.

It is perhaps too soon to say just what bearing the foregoing observations will have upon the explanation of the phenomena connected with new stars. It would seem, however, that such great velocities pointed rather to a violent collision of some sort than to an outburst within a dark and comparatively cool body; but whether a collision of a solid body with another, or the passage of a solid body through a gaseous nebula or a swarm of meteorites, is uncertain.

It may be that in the outburst of *Nova Persei* we have seen the formation of a nebula, either planetary or spiral.

Professor Wolf's photographs were obtained on August 23, and a comparison with his nebula would be valuable; but neither reproductions of his photographs nor the accurate coördinates of the nebula have been published.

Mr. Joel Stebbins, Fellow in Astronomy, assisted in taking the photograph with the Crossley reflector.

C. D. PERRINE.

NOVEMBER 10, 1901.

THE AMHERST ECLIPSE EXPEDITION TO SINGKEP, 1901.

By the generosity of Mr. Arthur Curtiss James, of New York, Amherst College was enabled to send out the sixth astronomical expedition in my charge.

Singkep (latitude 0° 30′ south, longitude $6^h\ 57^m$ east of Greenwich) was chosen because the chances of clear skies were not inferior to those of other available regions, as inferred from the very complete and carefully collected tables prepared by the Dutch Commission, under the direction of Major Muller and Dr. Figee.

Singkep is an island about fifteen miles across, and located off the east coast of Sumatra. It is tributary to the Dutch Residency of Riouw, and has frequent communication with Singapore, chiefly by means of the private steamer of the "Singkep Tin Maatschappij." This company and its fifteen mines occupy the island, and the officials of the company most courteously received the expedition as their guests.

The chief instruments were:

(*a*) The 12-inch Lyman speculum, freshly repolished by Brashear. (Focal length 15 feet, and diameter of Moon's image 1.8 inches.) This was mounted on an equatorial frame, with a long arm moved with great accuracy at one-half the rate of the Sun's diurnal arc-motion by means of a glycerine clock. The Sun's image therefore stood stationary upon the plates of the camera. This received the image directly without secondary refraction or reflection, and a little at one side of the cylinder of rays incident upon the mirror. This amount was found by experiment to be well within that which would produce harmful distortion. The camera was further provided with the facilities for exposing wet collodion plates, in addition to the ordinary gelatine dry plates. Also it was fitted with a frame, holding a revolving mechanical occulter, of the improved type described elsewhere.[1] The unusual duration of totality permitted preparation for nearly fifty exposures.

(*b*) A double polariscope with a 2-inch lens of 28 inches focus, prepared by Dr. Wright of Yale University. Number of exposures, six.

(*c*) A 3½-inch Goerz lens of 33 inches focus, fitted to my automatic camera, previously used in Japan and Tripoli, and loaded with 352 Lovell backed plates, 2 × 2½ inches.

By the courtesy of Messrs. Bausch and Lomb, the Goerz Optical Company, and the Gundlach Optical Company, the expedition was provided with many other lenses of varied dimension and focal length. Mr. Leonard W. Pope, of Amherst College, and Mr. Rijbering, of the Singkep Tin Company also lent (1) a 6-inch silvered glass mirror, and (2) a Leviathan lens. All of these, fortunately, were pressed into service, through the kind interest and thoughtfulness of Mr. H. P. Krull, manager of the Singkep Tin Company, who provided me with the necessary artisans for constructing improvised cameras.

The uncertain character of the weather rendered it advisable to scatter the instruments as much as possible. Six auxiliary stations were accordingly established — three of them on the island of Singkep itself, at distances of one, five and twelve miles from the main station; one on Pulo Laya nearly thirty miles southeast of Singkep, by the courtesy of Admiral Dekkers, commanding the Dutch government steamer *Flamingo*; one on Pulo Lalang, about fourteen miles south of Singkep, and one on Lingga, about the same distance north of Singkep, by courtesy of the Sultan of Lingga, who considerately lent his steam yacht *Dalel* for transportation of instruments and observers.

At the last station only were photographs of the corona secured, by Baron van Boetzelaer, the Assistant Resident located there. Totality was not entirely cloudless with him, but he made over thirty exposures with the improvised camera which I sent him, twenty-eight of which are useful, and eleven very good. Unfortunately they are small, the lens used being the back lens of 22 inches focus, belonging to the "Leviathan" lent by Mr. Rijbering. These lenses were originally of French manufacture, and mounted in London for Messrs. Robinson & Company, of Singapore. It is an excellent achromatic giving a sharp focus. These plates used were Ilford Rapid, and they show the corona of 1901 as slightly if at all divergent in general form from that of 1900.

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[1] *Monthly Notices Royal Astronomical Society*, 61, 531, 1901.

At all the other auxiliary stations, as well as at the main station in Singkep, clouds covered the corona, and no photographs could be taken. Nearly the whole forenoon had been radiantly clear, at all the stations. It was a dense cloud-bank slowly rolling over from the Sumatra coast, and rising higher and higher, that wrought the disaster.

Ten plates were exposed at the main station, prepared for the detection of any possible X ray effect in the coronal light, but no such action was discovered on developing them.

No observer at any of the stations saw the shadow-bands, except Madam van Boetzelaer, at Lingga, who reported them as having an oscillatory motion during a portion of totality. At my suggestion many observers in Singapore also looked for shadow-bands, as it is quite possible the bands should be visible a little outside the belt of totality, just as they can be seen at stations within the belt, but during the narrow crescent phase just before and after totality. Although the skies were perfectly clear at Singapore, however, no shadow-bands were seen there.

Meteorological observations of the type requested by Mr. A. Lawrence Rotch, of Blue Hill, were made on my request by Dr. Leicester of the hospital at Singapore, and at Singkep by Mr. H. Loriaux, representative of the Singkep Tin Company in Riouw.

Four observers were prepared with occulting disks suitably mounted to obscure the bright inner corona and enable them to catch the outer streamers, and six others to sketch the entire corona; but clouds precluded result.

A few interesting effects of totality upon the animal world were noted.

About an hour after contact III the sky cleared, and remained so till sunset; so that I secured contact IV.

I built anew a type of mechanical commutator for operating the photographic instruments automatically. Though simple in form and very inexpensive, it proved very competent for the purpose intended. and I have made it the subject of a separate paper elsewhere.

Also I have described the elaborate arrangements for utilizing the telegraph, to enable Mr. Maunder at Mauritius to dispatch an immediate message regarding his observations to the astronomers at Padang where totality came on an hour and a half later. The telegraph lines Mauritius, Zanzibar, Aden, Bombay, Madras, Penang, Padang were held open at the exact time requested, and expectantly for the Mauritius message—which might easily have gone through in ten to fifteen minutes. For the completeness of these arrangements the thanks of astronomers are due Mr. W. Grigor Taylor, General Manager Eastern Extension Telegraph Company at Singapore, who, at once on my suggestion, took the matter in hand with keen interest and genuine enthusiasm. The expected message was to convey some knowledge of—(*a*) the position of any comet or intramercurial planet seen, (*b*) the general form of the corona, (*c*) the abnormal brightness or faintness of the characteristic coronal line, (*d*) the general nature of the Mauritius results.

The message was actually dispatched last year, from Mr. Douglas's station in Georgia, to my own in Tripoli, in the very brief interval of twelve minutes; and the possibility of transmitting a similar message between remote stations this year in practically the same interval, have proven beyond a doubt the availability of the telegraph as an adjunct in eclipse research. There will never perhaps be time for the development of photographs; but certain optical observations are always possible, and worth the trouble of instant communication. Should the eclipse of 1905 fall total in Malta or Alexandria, the cable can again be called into service to notify observers there as to results secured in Spain.

Through the interest and assistance of Mr. van Dijk, of the Singkep Tin Company, I was enabled to carry out some preliminary experiments in the direction of securing eclipse observations at sea. These were favored by the fact that the ocean to the east of Singkep was nearly always motionless, and that the sky over it was cloudless at the eclipse hour during many more days than from any part of Singkep itself. Our experiments were confined to the construction of a triangular raft, the floating power being derived from six large oil drums. Had not the sea become too rough the night before to permit the safe use of so frail a craft, the expedition might easily have secured valuable photographs of the corona at sea, for about ten miles to the east the sky was unclouded during totality. I hope to have an opportunity to experiment with this method further, before the eclipse of 1904, which is almost wholly upon the waters of the Pacific. Our experiments at Singkep quite satisfied me that, unless the ocean is very rough, it is an unnecessary assumption that eclipse observations of value are wholly precluded at sea.

DAVID P. TODD.

THE SPECTRUM OF *NOVA PERSEI.*

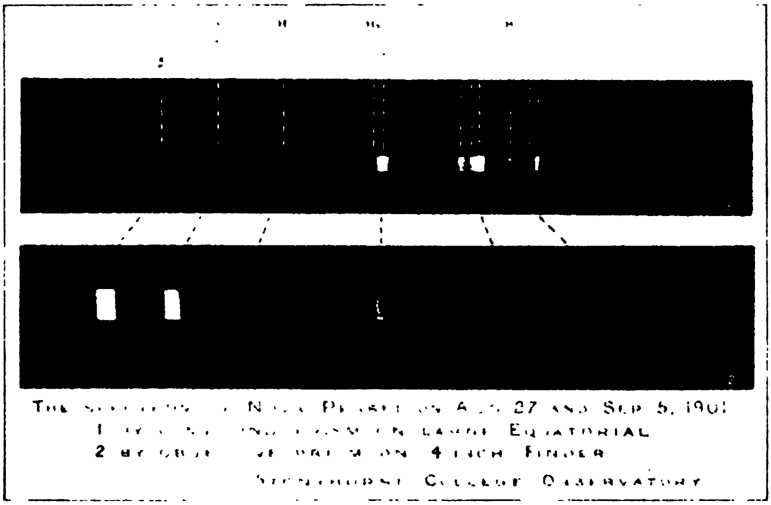
To the Editor of the ASTROPHYSICAL JOURNAL.

SIR: Please accept enclosed photographs of the spectrum of *Nova Persei.* You will see that the likeness to the Nebula 3918, mentioned by Professor Pickering in *A. N.* 3735, has improved as regards the lines 5007 and 4364. But is not the likeness spoiled by the great width of the fading hydrogen lines, and by the strong lines 3869, 3969, 4640, and 4713? And again, the *structure* of the three lines 3869, 3969, and 4364 is new. These lines are marked in the same manner, quite symmetrically, by four brighter lines crossing each, at the same spectral intervals. They are just discernible in the print, and are very clear on the negatives. They are stronger and clearer in the more refrangible lines in seven photographs taken between August 27 and October 6. They are distinct enough in the line 4364 on August 27, September 5, and October 6, but are lost on intermediate plates by want of light for the objective prism and by want of definition by the compound prism.

In my notes on the spectrum in March, which you kindly published in the ASTROPHYSICAL JOURNAL **13**, 4, I referred to a periodic change in the spectrum coinciding with the light changes. Since then I have been able to compare all my photographs of the spectrum with the magnitudes of the star as measured at the Radcliffe Observatory, Oxford; and it appears from these that the then new spectrum was connected, not with the minimum phase of the star's light curve, but with the absolute magnitude 4.57 of the Radcliffe measures. The older spectrum appeared always when the magnitude was greater, and the new spectrum when the magnitude was less than this figure; and the spectrum on April 9, when the magnitude was 4.57, had been already noted as partly of the old form and partly of the new form.[1] On this date the star was losing light, and the new blue band 4640 (oxygen triplet?) was beginning to form. On April 11 the new spectrum was complete; but the magnitude of the star was not obtained at the Radcliffe Observatory. On April 12, at magnitude 4.67, the

[1] *M. N.*, May 1901, note 4, on the spectrum of *Nova Persei.*

PLATE XXIII.


The Spectrum of Nova Persei on Aug 27 and Sep 5, 1901
1 [illegible] Equatorial
2 by [illegible] prism on 4 inch Finder
Stonyhurst College Observatory
2

Spectrum of *Nova Persei.*

new spectrum was also complete, the lines 3869 and 4364 being fully formed, and it was also complete on March 28, at magnitude 4.61. It seems, therefore, right to say that the lines 3869 and 4364 came into being at a temperature indicated by the light-magnitude 4.6.

But the line 3969 (at the position of $H\epsilon$) probably belongs to a lower temperature. It was in full strength on April 11, being then much stronger than $H\delta$; but we have not the measured magnitude for this, only my own note that the star was brighter on the 12th, when the magnitude was 4.67, and then the line was not in full form. It was again stronger than $H\delta$ on the 16th, at magnitude 5.32; it was not so on a later date, April 23, at magnitude 4.36, and it was not so on an earlier date, March 22, at magnitude 5.20. In this way the appearance of $\lambda 3969$, whether it be an abnormal state of hydrogen radiation or a new superposition, is connected with the temperature represented by the star's magnitude between 5.2 and 5.3.

If, therefore, temperature is the real cause of the intensity and structure of the star's light, there is a way of obtaining an absolute measure of the temperature of *Nova Persei* through its spectrum. For the temperature represented by the magnitude at the appearance of any one of these lines is the higher limit of the range of temperature within which the particular radiation is possible. It remains therefore to discover the true origin of any one of these three lines, and to find the higher temperature at which the line vanishes. It may never be possible to measure this temperature; but it would be something to know that a stellar temperature was an artificial possibility.

Yours faithfully,

WALTER SIDGREAVES.

STONYHURST COLLEGE OBSERVATORY,
October 17, 1901.

SPECTRUM OF LIGHTNING.[1]

PHOTOGRAPHS of the spectrum of lightning were obtained on July 18 and 21, 1901, by Mr. J. H. Freese, under the direction of Mr. Edward S. King. The eight-inch Draper telescope was used with an objective prism. The telescope was directed to the portion of the sky in which the lightning was particularly bright, and when the observer thought that he had obtained an image, the plate was changed. Even then many of the plates were badly fogged. A number of photographs were taken in this way, and showed the curious fact that the spectrum of lightning is not always the same. One flash, on July 18, showed three bright bands, while another taken on the same evening showed ten bright lines, and closely resembled one taken on July 21. The latter is shown in Plate XXIV. To increase the contrast of the original negative, a double contact print was made from it with slow plates, and is reproduced in the plate on the original scale. The brighter portion of a second flash, clearly seen in the original negative, also appears in the print. Measures, each consisting of three settings, were made of three portions of the principal spectrum, and the means of the results are given in Table I. The original negative was an isochromatic plate. The successive columns give the hydrogen lines with which certain of the lines are assumed to be identical, the mean wave-length and intensity of the lines in the spectrum of lightning, and the wave-length and intensity of the principal lines in the spectrum of *Nova Persei*, No. 2, on March 23, 1901.

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[1] *Harvard College Observatory Circular* No. 62.

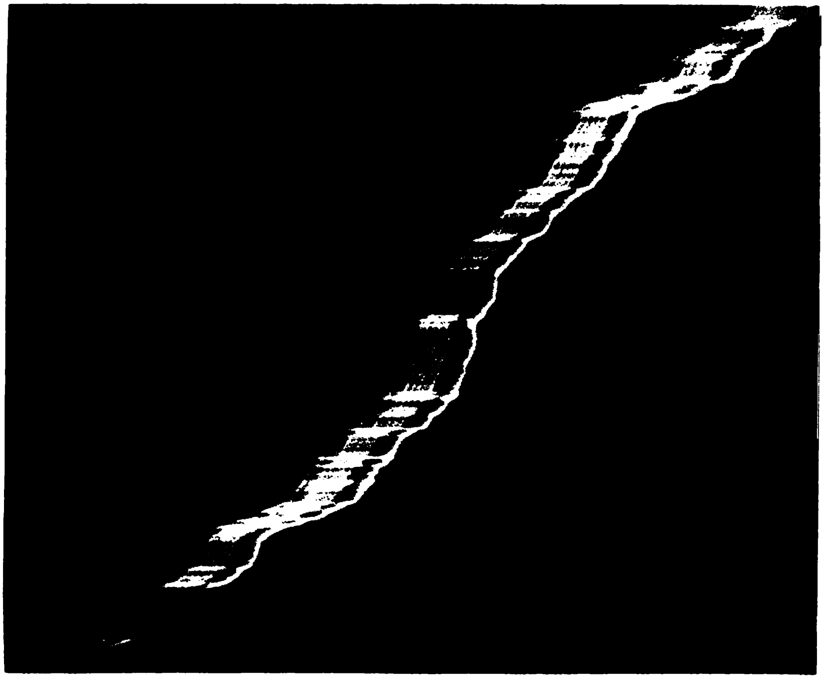
TABLE I.

SPECTRA OF LIGHTNING AND *NOVA PERSEI.*

Hyd.	W.-L.	Int.	W.-L.	Int.	Hyd.	W.-L.	Int.	W.-L.	Int.
Hη	....	..	3836	4	*Hγ*	4341	5	4341	10
Hζ	3881	10	3889	5		4441	?	4468	4
	3956	2	3970	7		4519	1	4573	3
Hε	3998	3				4643	8	4646	6
	4046	2	4030	2		4754	1	....	..
Hδ	4102	8	4102	8	*Hβ*	4861	5	4862	10
	4147	4	4149	1		4940	?	4925	1
	4187	?	....	..		5022	2	5015	3
	4222	5	R	2		5173	1	5171	3
	4263	1	....	..		5595	30	R	20

The first line in the spectrum of lightning is a broad, bright band, extending from wave-length 3830 to 3930, and is perhaps identical with the nebular line 3875. The line 4222 appears as a broad band in the *Nova*. The last band is very broad or perhaps a continuous spectrum extending in both objects from about wave-length 5300 to 6000. The lines in the two spectra appear to resemble each other closely both in position and in intensity. On September 15, 1901, a photograph was obtained with the eleven-inch Draper telescope, showing nearly thirty bright lines. Some of these show a curious doubling,

PLATE XXIV.



Spectrum of Lightning.

the separation varying in different portions of the flash. Apparently, this is due to another flash, in whose spectrum only a portion of the lines appear.

EDWARD C. PICKERING.

NOVEMBER 16, 1901.

MOTION IN THE LINE OF SIGHT.

The following letter, which has an important bearing on the history of astrophysics, is reprinted from the *Observatory* for December 1901:

GENTLEMEN: It is always with extreme reluctance that I write on any personal matter. In Sir David Gill's recent address at the Cape, printed in your last number, the statement appears that about 1865 my "attention was directed by Clerk Maxwell to this possibility of the new astronomy." (Determination of motion in the line of sight.)

So far from this having been the case, the method suggested itself to me directly from Doppler's work, sometime in 1862–3. Among the first words of my paper on the subject in *Phil. Trans.*, 1868, are the following: "We were fully aware at the time (1863) . . . . that these comparisons might serve to tell us something of the motions of the stars relatively to our system." (P. 529.)

The inclusion of Clerk Maxwell's letter in my paper came about in this way. Wishing to make the historical introduction to my paper as complete as possible I asked my friend, Clerk Maxwell, in 1867, to give me an account of some experiments which I had heard he had been making to detect the influence of motion on the refrangibility of light. His letter, which I did not receive until June 1867, appeared to me to be of so much interest that instead of making extracts from it I requested his permission to print it in full in my paper. Clerk Maxwell's reply, which I quote from a letter dated March 23, 1868, shows clearly that my work had been independent, and not undertaken in consequence of a suggession of his. His words are: "If it appears to you that what I sent you last summer would answer as part of your paper, it would be very agreeable to me to have it placed beside your work, so that if it should contain anything not applicable to your methods, or to which your methods are not applicable, the difference may be seen to be the effect of independent working, and not of opposition or criticism."

Yours faithfully,

WILLIAM HUGGINS.

UPPER TULSE HILL,
November 9, 1901.

REVIEWS

Recherches Expérimentales sur les Spectres d' Étincelles. Par G. A. HEMSALECH. Pp. 138. Paris: Hermann, 1901.

THIS volume deals with a subject which, at the present moment, is of especial interest to all spectroscopists, namely, the constitution of the electric spark. The earlier part of the book contains a clear and orderly account of all the more important work hitherto done along this line, while the later part of the volume gives a number of new and valuable results recently obtained by Mr. Hemsalech in the research laboratory of the Sorbonne, and offered by him as a thesis for the degree of Doctor in Science. The starting point of this latter work is the series of discoveries made jointly by Schuster and Hemsalech, and published in the *Phil. Trans.* **193**, 189–213, 1899, and in *Proc. Roy. Soc.*, **64**, 335, 1899.

These results may be briefly summarized as follows:

1. The ordinary Leyden jar discharge may be considered as made up of three parts or phases, namely: (1) an initial discharge, which opens up a luminous path by breaking down the air insulation and producing an air spectrum; (2) an "aureole" of metallic vapor filling the region between the electrodes, and remaining luminous long after the initial discharge is over; (3) a series of oscillatory discharges taking place in this atmosphere of metallic vapor as a medium, and giving rise to the characteristic metallic spectra.

2. The introduction of self-induction without iron serves to intensify the metallic spectra, and to weaken the air spectrum. By this means the air lines may be practically eliminated.

3. The introduction of resistance into the discharge circuit renders the discharge intermittent, deadbeat, and feeble.

4. All metallic lines are not affected in the same way by the introduction of self-induction — some are intensified, while others are weakened.

Starting upon this foundation, Hemsalech has added the following facts:

1. Metallic lines which disappear as the self-induction of the circuit

is increased do so by first becoming "short"—in Lockyer's sense—and then "shorter," and finally mere luminous points about the electrodes.

2. The effect of self-induction, affecting different lines in different ways, gives a basis for the division of the lines in spark spectra into three groups. The first of these groups includes all those lines which diminish rapidly as self-induction is increased. This class includes air lines and the "short" metallic lines which appear in the spark only. As typical lines the following are mentioned: *Mg* 4481.4, *Pb* 4244.9, and *Pb* 4386.6. The second group includes all lines which diminish slowly and gradually with increase of self-induction. Into this class fall those lines which are strong, and which are common to both spark and arc; in general they are reversed or nebulous. As types the *Mg* triplets at λ 5183 and at λ 3838 are cited. Into the third group he puts those lines which at first diminish in intensity, reach a minimum, afterwards increase considerably, and, having reached a maximum, again diminish. "Most of the lines in the spectra of iron and cobalt" are cited as typical of this class. Practically all of the lines in the series of Kayser and Runge belong in the second group.

3. Concerning temperatures of spark and arc, Mr. Hemsalech (p. 132) concludes that the first of the groups just mentioned contains the high temperature lines; that the second group includes those lines which are produced at the temperature of the arc and persist at a temperature much lower than that of the arc; and that the third group of lines is due to a temperature which is about that of the arc.

4. Concerning the fourteen different metals examined, namely: *Fe, Mn, Co, Ni, Cd, Zn, Mg, Al, Sb, Sn, Bi, Pb, Cu, Ag,* Mr. Hemsalech finds that they may be divided into two groups, according as most of the lines are increased or decreased in intensity, when the self-induction in the discharge circuit is increased. One of these groups includes iron and three of its related elements, *Mn, Co, Ni;* the other group contains all the rest of the fourteen elements mentioned above.

5. For each of these fourteen elements is given a table of the principal wave-lengths, accompanied by intensities in the ordinary spark, in the oscillating spark and in the arc.

H. C.

NOTICE.

The scope of the ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory. The subjects to which special attention will be given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric, and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

In the department of *Minor Contributions and Notes* subjects may be discussed which belong to other closely related fields of investigation.

Articles written in any language will be accepted for publication, but unless a wish to the contrary is expressed by the author, they will be translated into English. Tables of wave-lengths will be printed with the short wave-lengths at the top, and maps of spectra with the red end on the right, unless the author requests that the reverse procedure be followed. If a request is sent *with the manuscript* one hundred reprint copies of each paper, bound in covers, will be furnished free of charge to the author. Additional copies may be obtained at cost price. No reprints can be sent unless a request for them is received before the JOURNAL goes to press.

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